THE UNIVERSITY OF QUEENSLAND

BACHELOR OF ENGINEERING THESIS

PRODUCTIVITY OF A SURFACE MINER AT THE WILD OATS MINE

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Course Code: MINE4123

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UQ Engineering

Faculty of Engineering, Architecture and Information Technology
School of Mechanical and Mining Engineering

DISCLAIMER

For confidentiality, the name of the mine, coal sequence and operational pits have all been changed as per request from the client. The results contained within this Thesis are pro-rated to protect sensitive information including the productivity and operational cost of the surface miner. As such, the results are presented as a percentage of the target rate.

ABSTRACT

Surface miner machines allow for cutting, crushing and loading of material in one pass. Surface miners have been implemented in thin seam coal mining operations around the world, where minor improvements in the stripping ratio and operating cost increase the profitability of the project, with varying degrees of success. The Wild Oats Coal Mine has a surface miner operating on-site and since its incorporation as a major loading unit, the surface miner has not been analysed for productivity, performance or economic feasibility. The aim of this project was to analyse the Wirtgen SM4200 machine that is operating at Wild Oats to determine if targets for productivity and economic feasibility are being met throughout normal operation.

To achieve this, production data (both daily averages and instantaneous) were analysed by material type, location (block dimension) and operational cost. Two and a half years of data, in the form of six Excel spreadsheets, was used for the analysis. Anomalous data was removed from the data sets before they were collated and examined against targets rates of the unit.

The findings of the project concluded that the surface miner was able to reach a higher production rate and was more economical when cutting coal compared to interburden. An increased target production rate for coal of 13% and a reduced target for interburden of 10% was proposed. The lower partings were the least efficient and most costly due to the hardness of the material. The optimal practical cutting length was concluded to be 450 m and direct loading into haul trucks was the most efficient loading method. The effective productive utilisation was 60% for the surface miner.

Comparing conventional mining to the surface miner; in interburden less than 2 m thick the surface miner was 37% cheaper to operate, whereas in interburden thicker than 2 m, conventional mining would require blasting and thus the cost per bcm increased and the surface miner became 55% cheaper. Instantaneous data analysis showed that the surface miner was very effective and achieved average rates of 4.2 bcm/h (pro-rated) for milling coal and 3 bcm/h (pro-rated) for cutting interburden. Side casting proved to be less time effective as normal loading due to the rehandle component using the loader.

Overall for the coal mining industry, it was recommended that surface miner units are utilised in mines were coal seams are thick, as operational costs are low and production rates are high for this type of material.

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LIST OF ACRONYMS

ALARA	As Low As Reasonably Achievable
bcm	Bank Cubic Metre
CHPP	Coal Handling and Processing Plant
FMS	Fleet Management System
FTA	Fault Tree Analysis
KPI	Key Performance Indicator
ML	Mining Lease
NHG	New Hope Group
ROM	Run-of-Mine
SM	Surface Miner
UCS	Uniaxial Compressive Strength

1 INTRODUCTION

1.1 BACKGROUND

With ever developing technology in the mining industry, continuous surface miners now offer an effective alternative to conventional coal mining practices. Surface miner (SM) machines allow for cutting, crushing and loading of material in one pass. Whether SMs are used in conjunction with conventional load out units, or as a completely different mining method, the machine has the potential to favourably impact the economic viability of the reserve and the entire mining operation. It is for this reason that SMs lend themselves to selective mining and as this type of mining poses significant difficulties concerning the profitability of a mine, especially in a coal market that is fluctuating, SM technology now provides an inherent positive value. SMs have been implemented in thin seam coal mining operations around the world, where a minor improvement in the stripping ratio increases the profitability of the project, with varying degrees of success. As well as economic reasons, SM technology assists and relieves the pressure on drill and blast design, hauling, scheduling and environmental impacts.

1.2 PROBLEM DEFINITION

The Wild Oats Coal Mine has a SM operating on-site and since its incorporation as a major loading unit, the SM has not been analysed for productivity, performance or economic feasibility. As the mine operates conventional loading units as well as the SM, scheduling of the unit and planning for its implementation in specific areas of the mine where it can operate effectively has become problematic.

1.3 AIMS & OBJECTIVES

The aim of this project was to analyse the Wirtgen SM4200 machine that is operating at Wild Oats and investigate the findings of the four-month trial, to determine if the key performance indicators (KPIs) for productivity and economic feasibility are being met throughout normal operation. The project:

- investigated where the machine has been utilised productively by considering material type and thickness that has been cut and loaded, and block size (operating length) in which the machine has operated;

- investigated the ancillary equipment that is required to allow the SM to operate effectively – does the machine replace a wheel loader and two dozers as expected;
- calculated the associated operating costs and compared this to the cost of extracting the same material using conventional methods utilised elsewhere at Wild Oats;
- investigated the environmental advantages of the machine;
- researched other loading techniques (predominately side casting) that could be implemented at Wild Oats;
- recognised production advantages of using the machine as a major loading unit; and
- provided a recommendation on the most productive block size, material type and material thickness for the machine.

1.4 SCOPE

Through data collection of a Wirtgen SM4200 machine operating at the Wild Oats mine, the effectiveness of the loading unit was considered by examining:

- material type and thickness that the unit has been cutting and loading; and
- block size that the unit has been operating within.

These were analysed through the instantaneous cutting rate and long-term averages (which include machine breakdowns and operating delays) that the unit achieves throughout the mine site.

From examining the real data, projected data was modelled to optimise machine utilisation in terms of block size and material type (seam number). Other loading options were researched, including:

- side casting and windrowing to reduce the reliance on direct truck loading; and
- parking the unit when optimal cutting material is not available.

From these scheduling options, a model was used to estimate the cost per bank cubic metre (bcm) for the operation of the unit in different areas of the mine and compare this with baseline data of conventional extraction methods implemented at Wild Oats. This provided an achievement profile of the unit (in production terms) that can be compared to the numbers that were collected during the four-month trial.

Technical, environmental and socio-economic advantages of the machine and the core risks involved in operating a SM alongside a fleet of conventional open cut equipment were identified and a recommendation on the most productive block size, material type and material thickness for the machine was provided as per request from the client.

1.5 METHODOLOGY

1.5.1 *Analytical Research*

Productivity data of the SM was collected from the Wild Oats Coal Mine and was analysed to provide the foundation for recommendation. All production data from the past 2.5 years of operation was used for the general results; however, the sample size was limited when focusing on elements of the project. The data was sorted and anomalous results were excluded from the analysis and decision-making process. Working with industry professionals acted as quality assurance and control of the data results.

1.5.2 *Descriptive Research*

Journal articles, books, conference proceedings, past theses, websites and personal communication research sources were used to complete these sections of the project. The research that was undertaken encompasses coal mines that use SMs, Wirtgen SM units in production throughout the industry and the Wild Oats Coal Mine. Each source was annotated to provide a clear understanding of each reference and its individual use throughout the project's timeline.

1.6 INDUSTRY RELEVANCE, GAP IN KNOWLEDGE & EXPECTED OUTCOMES

The SM utilisation and implementation at Wild Oats is relatively new and innovative when compared to the rest of the Australian coal mining industry. With the Wild Oats' unit being the only operating SM in Queensland, the relevance of this topic is that it provides the New Hope Group (NHG) with specific information and results related to the operation. In theory, the method lends itself to highly selective mining, which can dramatically improve run-of-mine (ROM) coal quality, reduce dilution and increase reserve. These reasons were considered major advantages for the purchasing of the SM and as the unit has the potential to reduce the operating cost of loading, hauling and processing, the machine has obvious benefits.

Although these advantages have been postulated, the Wirtgen SM4200 has not been extensively analysed regarding productivity rates, locations and varying geological conditions with which the unit contends. An appropriate analysis and evaluation allows for a performance baseline for future operation and improvement projects.

The expected outcomes from this research project were:

- higher production rate when cutting and loading coal compared to interburden;
    - lower operating cost when implemented on coal.
- longer operating blocks provide higher production rates due to increasing the time before turning around; and
- side casting and windrowing provide an operational advantage to the unit; however, for complete implementation of this method there may be associated disadvantages which impact other areas of the mining process.

2 PROJECT MANAGEMENT

2.1 INTRODUCTION

To guarantee completion of the project within the allotted time frame and to the highest quality, a project management plan was defined with the intent to be used by key stakeholders to ensure each project deliverable was completed. The plan included a schedule of milestones, related resources, a budget, a project delivery risk assessment as well as a contingency plan.

2.2 PROJECT STAKEHOLDERS

The project required key stakeholders for the successful delivery of the key tasks and milestones, these include:

- Project Manager – an undergraduate Mining Engineer accountable for ensuring the completion of the project within the fixed timeframe.
- Project Supervisor – an academic professional who supervised and provided guidance in completing the agreed objectives and provided feedback based on defined project criteria.
- Technical Supervisor – a NHG representative who oversaw the technical guidance and information required for the completion of the project.

2.3 PROJECT DELIVERABLES

At the completion of the project, the key deliverables were:

- a written document that will constitute a Bachelor of Engineering Thesis which includes the background of the work performed and project outcomes;
- a collection of data analysis spreadsheets; and
- an AusIMM conference paper.

2.4 PROJECT KEY TASKS

The key tasks that were required for the completion of the research project were separated into two timeframes: Semester One (27/02/17 to 03/06/17) which included completed tasks in

MINE4122 and Semester Two (24/07/17 to 28/10/17) which includes completed and future tasks for MINE4123.

2.4.1 *Semester One*

The semester one tasks that were completed include:

- obtained insight to the field of study by gaining first-hand knowledge of the mine and Wirtgen SM before study commenced;
- reviewed available literature;
- confirmed research topic with site supervisor;
- collected and completed preliminary analysis of available data; and
- developed and reviewed scope of work.

2.4.2 *Semester Two*

Tasks that have been completed in semester two include:

- critically evaluated the results;
- presented findings of the analysis for submission in report and in formal seminar; and
- developed recommendations according to the findings.

Tasks that require completion include:

- develop conference paper to summarise the project.

2.5 PROJECT MILESTONES

Major milestones were identified as per the key parameters required to complete the research project. The milestones were separated by semester, with the semester one milestones including:

- confirmation of research topic and scope of study;
- submission of research project proposal;
- submission of annotated bibliography; and
- submission of project progress report.

The semester two milestones include:

- completion of data manipulation and analysis;

- review of final research and findings;
- presentation of Thesis findings in seminar;
- submission of examiner's copy of Thesis; and
- submission of AusIMM conference proceedings paper.

2.6 REQUIRED RESOURCES

The required resources used to complete the research are displayed in Table 1.

Table 1
Resources required to complete the project.

Resource	*Status*
Contact with site	Complete
Access to daily production data	Complete
Access to instantaneous production data	Complete
Access to machine specifications	Complete
Access to budget and costing information	Complete
Access to MineScape, Excel and JMineops	Complete

2.7 PROJECT BUDGET

The total expenditure of the research project was expected to be approximately $21 000. This accounts for researcher's wages during vocational work and throughout the year, estimating the actual time spent working on the project. The research was relatively inexpensive due to the ease of data collection and the availability of software (for which licences were not accounted for). Also, wages for the industry professional and academic supervisor have not been considered in this budget. Table 2 contains the project costs.

Table 2
Itemisation of project costs.

Expense	*Expected cost ($)*
Wages:	
2016/17 summer vacation work	5000
Semester one 2017	5000
2017 June/July holidays	5000
Semester two 2017	5000
Travel expense to site	800
Printing of reports	200
Total	21 000

2.8 PROJECT SCHEDULE

The research project schedule operated for the duration of The University of Queensland's 2017 academic calendar. Figure 1 on the following page, displays the Gantt chart which outlines the key dates that were used to complete each task.

The schedule included ongoing tasks, such as:

- consultation with industry and academic supervisors, throughout the year; and
- collecting data which was organised through personal communication with industry professionals.

Semester one tasks highlight the importance of continual work required to produce the progress report. Semester two key milestones identify dates for submission of each of the assessment pieces. As evident in Figure 1, a generous timeframe was allowed for the completion of each task to account for any difficulties, additional commitments and revision before the final submission. All tasks have been completed prior to the conference paper assessment piece.

2.8.1 *Critical Path*

From the project milestones identified in Section 2.5, a detailed project schedule was developed for the period between 21/11/16 and 18/11/17. Outlined in Figure 1, the tasks that were deemed critical include:

- weekly consultation with supervisors;
- consultation with site;
- data analysis (throughout project);
- submission of project plan agreement;
- extensive data analysis (midyear break); and
- preparation and submission of examiner's copy of Thesis.

ID	Task Name	Duration	Start	Finish	% Complete
1	**Mining Research Project**	**198 days**	**Thu 16/02/1**	**Sat 18/11/1**	**98%**
2	**Ongoing Project Tasks**	**199 days**	**Wed 15/02/**	**Sat 18/11/1**	**100%**
3	Collecting data	120 days	Thu 16/02/1	Wed 02/08/	100%
4	Weekly Consultation with Supervisors	198 days	Thu 16/02/1	Sat 18/11/1	100%
5	Consultation with Site	261 days	Mon 21/11/	Sat 18/11/1	100%
6	Data Analysis	74 days	Wed 01/02/	Sun 14/05/1	100%
7	**Semester One**	**69 days**	**Mon 27/02/**	**Thu 01/06/1**	**100%**
8	**Research Project Proposal**	**16 days**	**Thu 02/03/1**	**Thu 23/03/1**	**100%**
9	Research Literature	13 days	Thu 02/03/1	Sun 19/03/1	100%
10	Confirmation of Thesis Topic	1 day	Thu 02/03/1	Thu 02/03/1	100%
11	Writing Report	12 days	Fri 03/03/17	Sun 19/03/1	100%
12	Review Report	3 days	Mon 20/03/	Wed 22/03/	100%
13	Submission	1 day	Thu 23/03/1	Thu 23/03/1	100%
14	**Annotated Bibliography**	**19 days**	**Fri 24/03/17**	**Wed 19/04/**	**100%**
15	Research Literature	5 days	**Fri 24/03/17**	Thu 30/03/1	100%
16	Writing Report	10 days	Fri 31/03/17	Thu 13/04/1	100%
17	Review Report	3 days	Fri 14/04/17	Tue 18/04/1	100%
18	Submission	1 day	Wed 19/04/	Wed 19/04/	100%
19	**Project Progress Report**	**25 days**	**Fri 14/04/17**	**Thu 18/05/1**	**100%**
20	Research Literature	8 days	**Fri 14/04/17**	Tue 25/04/1	100%
21	Writing Report	14 days	Wed 26/04/	Sun 14/05/1	100%
22	Review Report	3 days	Mon 15/05/	Wed 17/05/	100%
23	Submission	1 day	Thu 18/05/1	Thu 18/05/1	100%
24	**Project Plan Agreement**	**10 days**	**Fri 19/05/17**	**Thu 01/06/1**	**100%**
25	Preparation of Plan	9 days	Fri 19/05/17	Wed 31/05/	100%
26	Submission	1 day	Thu 01/06/1	Thu 01/06/1	100%
27	**Mid Year Break**	**47 days**	**Sat 20/05/1**	**Sun 23/07/1**	**100%**
28	Reschedule Project Schedule Gannt Ch	3 days	Thu 18/05/1	Mon 22/05/	100%
29	Extensive Data Analysis	48 days	Mon 15/05/	Wed 19/07/	100%
30	**Semester Two**	**76 days**	**Mon 24/07/**	**Mon 06/11/**	**88%**
31	Supervisor Consultation	76 days	Mon 24/07/	Mon 06/11/	100%
32	**Seminar**	**39 days**	**Mon 24/07/**	**Thu 14/09/1**	**100%**
33	Synopsis	30 days	Mon 24/07/	Fri 01/09/17	100%
34	Preparation of Presentation	7 days	Mon 04/09/	Tue 12/09/1	100%
35	Slide Submission	1 day	Wed 13/09/	Wed 13/09/	100%
36	Present	1 day	Thu 14/09/1	Thu 14/09/1	100%
37	**Examiner's Copy of Thesis**	**56 days**	**Mon 24/07/**	**Mon 09/10/**	**100%**
38	Summarise and Write Results	29 days	Mon 24/07/	Thu 31/08/1	100%
39	Write Conclusions	3 days	Fri 01/09/17	Tue 05/09/1	100%
40	Write Abstract	4 days	Wed 06/09/	Mon 11/09/	100%
41	Finalise References	2 days	Tue 12/09/1	Wed 13/09/	100%
42	Format Report	5 days	Thu 14/09/1	Wed 20/09/	100%
43	Review Draft One	5 days	Thu 21/09/1	Wed 27/09/	100%
44	Review Draft Two	5 days	Thu 28/09/1	Wed 04/10/	100%
45	Final Amendments and Review	3 days	Thu 05/10/1	Sat 07/10/1	100%
46	Printing and Binding	1 day	Sun 08/10/1	Sun 08/10/1	100%
47	Submission	1 day	Mon 09/10/	Mon 09/10/	100%
48	**Conference Paper**	**14 days**	**Tue 10/10/1**	**Fri 27/10/17**	**0%**
49	Write Paper	10 days	Tue 10/10/1	Mon 23/10/	0%
50	Review Paper	3 days	Tue 24/10/1	Thu 26/10/1	0%
51	Submission	1 day	Fri 27/10/17	Fri 27/10/17	0%
52	**Revised Copy**	**9 days**	**Wed 25/10/**	**Mon 06/11/**	**0%**
53	Review Examiner's Copy	9 days	Wed 25/10/	Sun 05/11/1	0%
54	Make amendments	1 day	Mon 06/11/	Mon 06/11/	0%

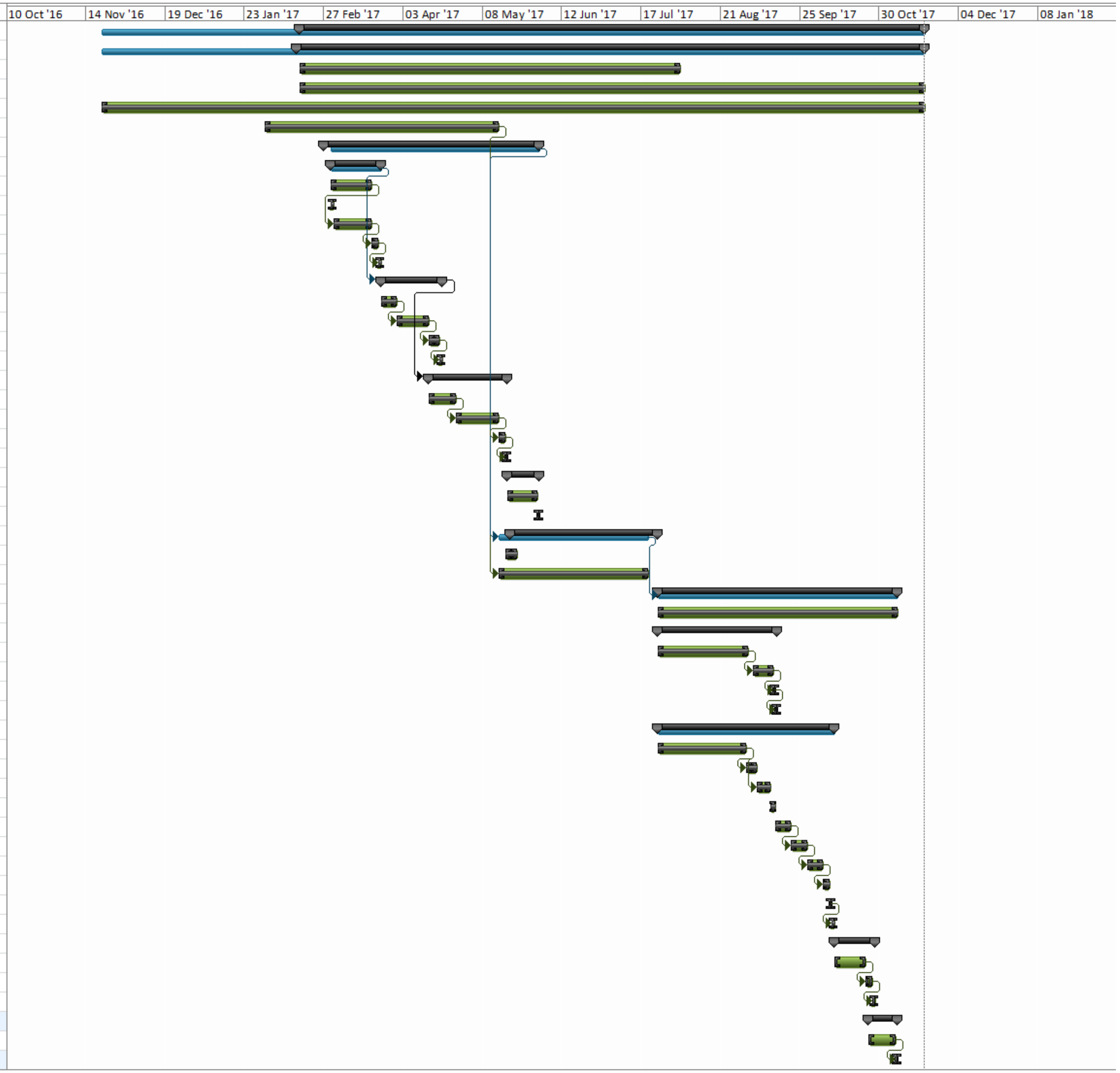

Figure 1. Project Gantt Chart.

2.9 PROJECT DELIVERY RISK ASSESSMENT

2.9.1 *Introduction*

The process of identifying risks using a risk assessment matrix is crucial in project planning and risk management. As well as the critical path and Gantt chart (as detailed in Section 2.8.1), inherent risks concerning timeframes and the completion dates needed to be considered. A standard risk assessment matrix (Table 3) was used with likelihood and consequence both contributing to the overall risk of the identified hazard. From this analysis, failure mechanisms and mitigation strategies for this project were determined. Tables 4 and 5 define the likelihood and consequence categories respectively.

Table 3
Risk assessment matrix.

Likelihood	*Consequences*				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	11	16	20	23	25
Likely	6	12	17	21	24
Moderate	3	8	13	18	22
Unlikely	2	5	9	14	19
Rare	1	4	7	10	15

Source: NOST (2012)

Table 4
Definition of hazard likelihood categories.

Likelihood	*Description*
Almost Certain	The event is expected to occur in most circumstances (weekly)
Likely	The event will probably occur in most circumstances (1 – 12 months)
Moderate	The event should occur at some time (1 – 5 years)
Unlikely	The event could occur at some time (5 – 50 years)
Rare	The event may occur in exceptional circumstances (50 – 100 years)

Source: NOST (2012)

Table 5
Definition of hazard consequence categories.

Consequence	*Description*	*Process Interruption*
Insignificant	No impact	<1 hour
Minor	Slight time loss, minor reduction in project quality	1 hour
Moderate	Major time loss, significantly	1 day
Major	Not expected to occur	1 week
Catastrophic	Is expected to occur in exceptional circumstances only	>1 week

Source: NOST (2012)

A fault tree analysis (FTA) was developed to identify, model and evaluate the project, as reported by Marshall (2012), in terms of:

- potential faults;
- modes and causality of faults; and
- quantifying the faults' contribution to system unreliability during product design.

2.9.2 *Hazards Affecting Project Completion*

Table 6 contains identified hazards that could have impacted upon the completion of the project. The risk assessment matrix was utilised to develop the risk rating for each of the identified hazards.

Table 6
Hazards and their respective risk ratings related to project completion.

Hazard	*Likelihood*	*Consequence*	*Risk Rating*
Failure of data storage	Moderate	Catastrophic	22
Delay in printing	Likely	Major	21
Submission is missing	Unlikely	Catastrophic	19
Industry supervisor not available for consultation	Unlikely	Major	14
Poor quality of work	Unlikely	Major	14
Traffic delays/transportation issues on due dates	Unlikely	Moderate	9
Insufficient reference material	Unlikely	Moderate	9
Lost time due to illness or injury	Unlikely	Moderate	9
Changing scope of project resulting in time constraints	Unlikely	Moderate	9
Insufficient data available for analysis	Moderate	Minor	8
Data credibility of analysis	Moderate	Minor	8

2.9.3 *Fault Tree Analysis*

A FTA was developed for the research project to identify the critical path of all tasks that were integral for the completion of the project. This tool identified failure and unexpected outcomes and events to highlight the potential risks associated with the research project. For simplicity, the FTA was separated into semester one and semester two tasks; thus, failures and problems for both Mining Research Project I and Mining Research Project II courses were assorted into the same FTA. From this, controls and mitigation strategies (contingency plans) have been developed to address the identified modes of failure. Figure 2 on the following page contains the FTA.

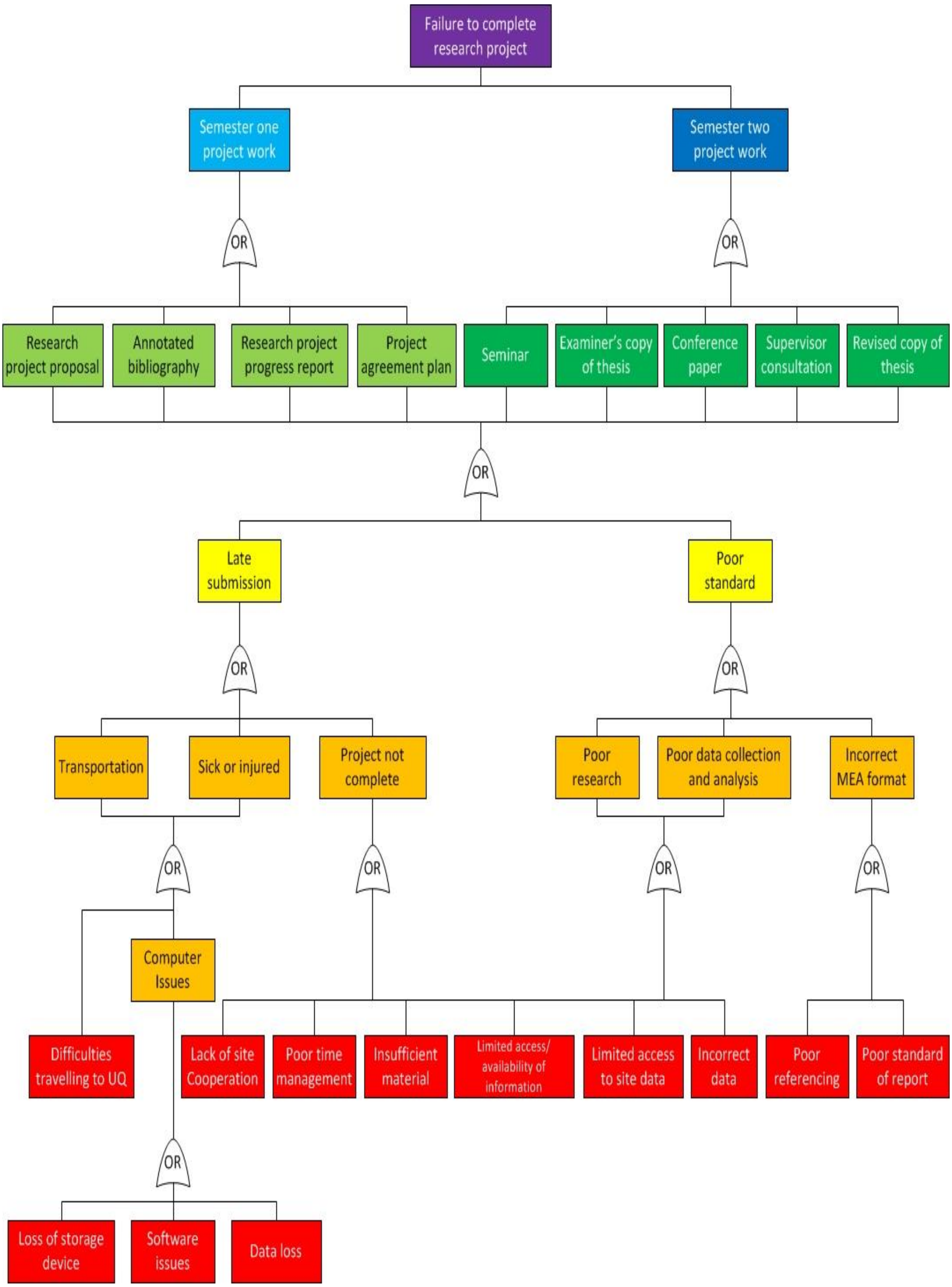

Figure 2. Fault tree analysis.

2.9.4 *Contingency Plans*

The risk assessment analysis and FTA effectively identified methods of failure and aided in the creation of a management strategy for potential hazards. Table 7 below contains mitigation strategies to reduce the risk to an acceptable level.

Table 7
Contingency plans and evaluated risk ratings for identified hazards.

Hazard	*Risk Rating*	*Control/Mitigation Strategies*	*Evaluated Risk*
Failure of data storage	22	• Back-up documents on multiple storage devices: hard drive, USB and external hard drive • Use reliable computers • Look after personal computer	5
Delay in printing	21	• Allow a day for printing in project schedule – day before the examiner's copy is due	1
Submission is missing	19	• Save document on multiple storage devices • Allow one day for printing • Confirm submission with UQ supervisor	1
Industry supervisor not available for consultation	14	• Working on-site during semester one, mid-year break and semester two ○ Allows for face-to-face communication regularly	4
Poor quality of work	14	• Ensure schedule is effective in time management • Use of high quality references • Correct use of references • Allow sufficient time to proof read work	5
Traffic delays/transportation issues on due dates	9	• Allow excessive time to travel to UQ • Have a second plan of getting to UQ if parking may be an issue at UQ • Print hard copy the day before submission	1
Insufficient reference material	9	• Ensure annotated bibliography is completed to a high standard • Continue to reference as new sources are used throughout writing the report	4
Lost time due to illness or injury	9	• Maintain healthy lifestyle, for optimal physical and mental health	5
Changing scope of project resulting in time constraints	9	• On-going consultation with UQ and industry supervisors • Regular research and reviewing of project tasks • Review project aims regularly and adjust accordingly	3
Insufficient data available for analysis	8	• Allow for sufficient time to both gather and analyse data ○ Already gathered data – reduction of risk	1
Credibility of data analysis	8	• Use reliable references and utilise all references effectively throughout the project • Review project aims regularly and adjust both the aims or data analysis accordingly	3

The implementation of the controls listed in Table 7 was critical to the success of the research project. The contingency plan identified potential problems that may have affected the project and provided a comprehensive range of strategies that were implemented. The contingency plan outlined in Table 7 in conjunction with the project schedule outlined in Figure 1, optimised project completion within the timeframe. From the contingency plan (Table 7), it was deemed that the hazards with the highest evaluated risk (once controls were implemented) were:

- failure of storage device;
- poor quality of work;
- lost time due to illness and injury;
- industry supervisor not available for consultation; and
- insufficient reference material.

Even so, the risk of these hazards was reduced to as low as reasonably achievable (ALARA) on the risk matrix (NOST, 2012) and did not pose a threat to the completion of the project.

The contingency plan was used throughout the project to maintain low risk levels, such as the draft copies of the Thesis and data analysis sheets were saved to multiple hard drives and online to ensure the files were retrievable. To guarantee the Thesis was completed to a high standard and with the risk being ALARA, there was adherence to all dates for tasks as outlined in the Gantt chart.

3 WILD OATS COAL MINE

3.1 BACKGROUND

The Wild Oats Thermal Coal Mine is located approximately 160 km west of Brisbane in South East Queensland (Appendix 1). Wild Oats is owned and operated by the NHG and mining commenced in 2002 utilising surface coal mining strategies. The mine is currently utilising surface mining methods that are innovative for the coal mining industry. The coal sequence which is mined at Wild Oats is separated by major interburden and thus, requires highly selective mining practices to remove both interburden and coal with minimal dilution. Wild Oats has a dry climate with hot summers and cold winters, and is also subjected to heavy rainfall events during the wet season in summer.

3.2 OPERATION

NHG is an Australian owned and operated Energy Company (NHG, 2017a) which has owned the Wild Oats Mining Lease (ML) since 2002 and has operated the mine since this time. The mine began with a single pit (Pit 1) but now has three operational pits (Pit 2, 3 and 4). Wild Oats is a strip mine, with each pit split into conventional 150 m x 150 m mining blocks. The mine currently produces 4.7 Mtpa of thermal coal averaging a yield of 50% for all the coal seams. A majority of the product coal is exported internationally with some domestic sales making up the total coal produced. With a mine expansion on the horizon, meaning more satellite pits, an increase in stripping ratio and higher production per year, the mine's facilities and equipment require upgrading.

3.3 GEOLOGY

3.3.1 *Overview*

The thermal coal deposit is located within the Clarence-Moreton Basin within the lower Walloon sequence (NHG, 2017b); Appendix 1 shows the location of the deposit. Wild Oats currently mines the 30 m to 60 m thick Winx sequence, which is split into six nominated seam groups identified in descending stratigraphic order as A to F, each with up to 10 plys. Throughout the sequence major and minor interburden are present with both the interburden and coal seams varying in thickness. Figure 3 is an example of a cross section of the Winx sequence found at Wild Oats. The cross section indicates the problems that Wild Oats faces; the coal seams are undulating in nature, are not evenly stacked on top of each other and large faults are apparent throughout the area. In reference to Figure 3, the coals seams are labelled from the surface down; thus, the 'A' coals are indicated by light blue, the 'B' coals are indicated by red, 'C' coals by green, dark blue represents 'D' coals, 'E' coals by gold and the final 'F' seams in the Winx sequence are represented by pink. The Makybe coal seams are located, as Figure 3 indicates, approximately 40 m below the Winx sequence; thus, these seams are currently uneconomical to mine using open cut mining methods. Therefore, Wild Oats only mines the top six seam groups.

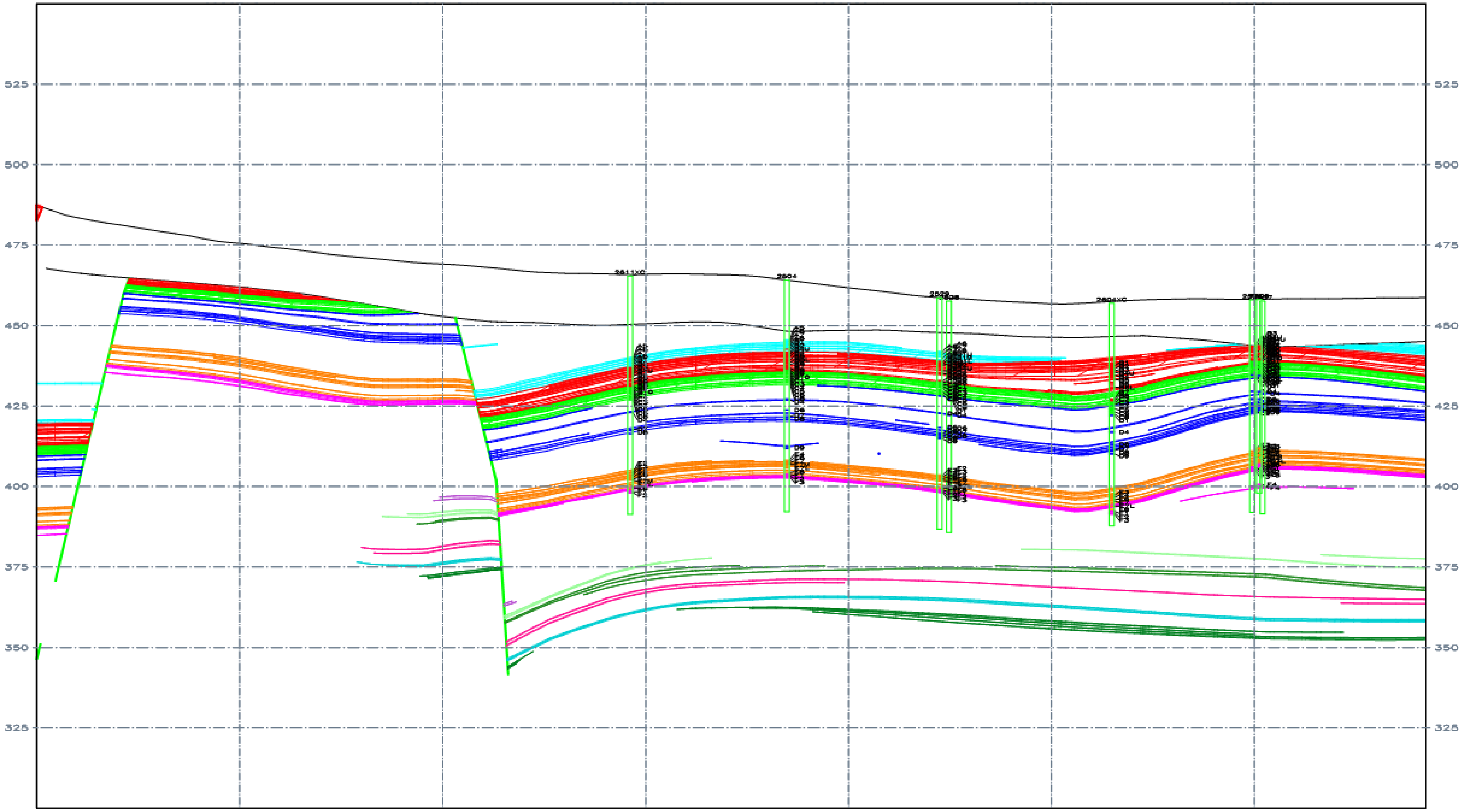

Figure 3. Cross section of Winx sequence
(NHG, 2012).

3.3.2 *Coal*

As seen in Figure 3 and Appendix 2, the thickness of the various coal seams is highly inconsistent and both images only indicate a section of Wild Oats. The coal seams vary throughout each of the mining pits, meaning that extensive exploration drilling and experienced coal quality supervisors are required to examine all coal seams as they become exposed, to measure thicknesses and tonnages for each of the seams in the operating block. However, some broad guidelines are used as a means of mine planning. Table 8 contains a summarised version of the Winx sequence at Wild Oats. The seam/bulk mining sequence offers an explanation to the mining method implemented and the importance of blending poor quality coal to increase production. This means that either a coal seam can be mined separately, implementing selective mining, or as a bulk sequence where seams are blended together. Due to the presence of interburden bands and varying coal quality and thickness, selective mining is predominately used within the mine, but when the coal seams are stacked on top of each other (with minimal interburden present) bulk mining sequences are implemented throughout the mine.

Table 8
Coal summary of the Winx sequence.

Sequence	*Seam/Bulk Mining Sequence*	*Thickness (mm)*	*Comments*
A	A2	600	Very inconsistent – not usually mined.
	A4-A8	3000	Partings bands varying in thickness.
B	B1-B6	4000-7000	Band of partings approx. 1 m thick can come in at B4 level requiring this sequence to be split into B1-B4 and B5-B6.
	B8-C1	1000-2000	Poor quality but consistent throughout the mine.
C	C3	300-400	Consistent throughout the mine and mined as a single seam.
	C5	800-900	Consists of several (up to six) bands.
	C6	400-500	Turning point of poor quality coal to high quality. As a generalised rule, all the seams below C6 are high quality. Consists of normally three bands.
	C8	300-700	Consistent throughout the mine and mined as a single seam.
D	D4	300-500	Consistent throughout the mine and mined as a single seam.
	D5	300-400	Consists of normally three bands.
	D6	300-800	Consists of two bands.
	D7	300-1000	Most unreliable seam. Consists of multiple bands.
	D8	400-1000	Consistent throughout the mine and mined as a single seam.
E	E2-E4	700-900	Consists of multiple bands. Thickness of coal and interburden vary.
	E5	300	Only found in Pit 2.
	E6	0-100	Sometimes too thin to warrant mining. Mined as E6-E7.

	E7	500	Thickness varies immensely. Lower, middle and upper seams are generally stacked on top of each other, or separated by bands. Sometimes one or two seams are not worth mining. Mined as E6-E7.
	E8	500	Can be a blocky material and therefore un-minable.
F	F1-2	150-200	Consists of two seams of coal separated by clay band which can be split out to improve quality.
	F3	300	Good quality.

Source: NHG (2012)

3.3.3 *Interburden*

As Table 8 indicates, many of the coal seams at Wild Oats are separated by thin bands of interburden; however, only the major interburden will be examined as the thin bands are too variant throughout the operation. Below in Table 9, the major interburdens are summarised.

Table 9
Interburden summary of Winx sequence.

Sequence	*Interburden*	*Thickness (mm)*	*Comments*
A	A8	100	Claystone.
B	B1-B6	varies	Coal seam is heavily interbanded, sometimes whole seam is taken as waste.
	B8	300-400	One band of claystone and one of siltstone.
C	C3	150-200	Consists of bentonite. Very hard interburden cap on top of C3 coal.
	C5	300-400	Bentonite plus 300 mm of parting (C4 coal).
	C6	50	Claystone.
	C8	50	Can increase to 4 m thick in areas.
	D4	>2000	Contains three coal stringer bands. Varies greatly in thickness either ripped or stacked or blasted. Mudstone.
D	D5	>2000	Varies greatly in thickness either ripped and stacked or blasted. Mudstone.
	D6	50	Can be up to 2 m thick in Pit 2. Claystone.
	D7	50-150	Siderite can sometimes be present.
	D8	100	Mudstone.
	E2	>2000	Mudstone with E1 coal stringer. Can be ripped and stacked or blasted.
	E5	400	Siltstone. Can be a part of E6 interburden.
E	E6	300-3500	Varies between ripped and stacked to requiring blasting. Siltstone.
	E7	>2000	Can be ripped and stacked or blasted. Siltstone.
	E8	400-600	Mudstone band below E7 coals and bentonite claystone above E8 coal.
F	F1	150	Rare occasions can increase to 500 mm. Claystone.
	F3	1000	Hard claystone.

Source: NHG (2012)

3.4 Mining Method

3.4.1 *Topsoil and Overburden*

Topsoil is removed by dozers and loaded into trucks using wheel loaders. The varying overburden and undulating topography makes pit configuration and wall design integral to operating the mine safely. Table 10 contains a summary of the overburden strata.

Table 10
Overburden material.

Rock Type	*Rock Strength*	*Description*
Sandstone/siltstone	Very weak to weak	Highly weathered, yellow with brown clays. Occasional formations of siderite within the weathered material.
Basalt	Hard and strong	Slightly weathered, dark grey, massive.

Source: NHG (2014)

Due to the presence of the hard basalt most blocks require the overburden to be drilled and blasted to loosen the overburden material. Overburden thickness ranges from approximately 5 m to 40 m depending on the surface topography and which coal seam is deemed the first seam to exploit. Overburden is usually removed by one of the two large excavators; however, the SM has been used to remove overburden. The SM has the capability to mill the overburden material at Wild Oats. Keeping in mind that the drum is a ‘coal’ drum, application in the strong basalt material is ineffective. Furthermore, the SM also has issues with milling moist clay material as it bogs the conveyor rollers. Use in this material requires close monitoring of the machine and the subsequent clay build up that may occur (NHG, 2014).

3.4.2 *Coal*

Coal is typically ripped and stacked by dozers and loaded out by wheel loaders into haul trucks with coal trays designed to dump material into the Coal Handling and Processing Plant’s (CHPP’s) bins. Depending on the coaling area and pit configuration, the SM cuts and loads coal efficiently into coal trucks; however, Wild Oats does not frequently implement side casting or windrowing loading techniques with the SM.

3.4.3 *Interburden*

As seen in Section 3.3, the thickness, type and hardness of interburdens vary between coal seams and throughout the mine. For instance, the D5 interburden may be 10 m thick in Pit 3 but is non-existent in Pit 4 and to complicate the selective mining process even more, interburden in different blocks in the same pit vary in thickness. This means that some interburden requires drill and blasting while others only require ripping. Rip and stack methods are utilised for partings less than 2 m thick and blasting is required when thickness is greater than 2 m. The rip and stack method has proved effective due to the extensive experience of dozer operators in separating coal from parting, but the process also requires three separate steps and at least three equipment units (2 dozers and 1 loader). For this reason, the SM is able to reach production targets whilst milling interburden, however is limited by the thickness and type. Even so, the SM is able to cut all the interburden at Wild Oats with varying success and production rates.

4 SURFACE MINING EQUIPMENT

4.1 WILD OATS FLEET

The SM fleet at Wild Oats is currently one Wirtgen SM4200. The SM operates alongside conventional load out units including:

- two large excavators;
- two large wheel loaders; and
- two smaller excavators and two smaller wheel loaders for general mine site use and occasionally as loading units.

Twenty-four haul trucks are on-site, of varying sizes and trays, including:

- 133 t;
- 181 t; and
- 218 t.

4.2 WIRTGEN SURFACE MINERS

4.2.1 *Introduction*

Wirtgen is the global market leader for the manufacture of machines for cutting rock in open cast mining operations (Wirtgen Group, 2016a). SMs made by the German company, Wirtgen, are being used as a primary cutting and loading unit in operations mining the following resources:

- coal;
- gypsum;
- iron ore;
- salt;
- phosphate;
- bauxite;
- limestone; and
- granite.

According to Wirtgen Group (2016a); SMs, just like all mining equipment, are one link in the mining chain, but SMs have a vital influence on the final result, as well as, innovating the entire mining process. Wirtgen Group (2016a) SMs are able to achieve this through three hallmarks of design:

1. Selective mining.
    a. Precise adherence to desired cutting depth is ensured through an automatic levelling system: this allows thinner seams to be mined with minimal dilution and with maximum accuracy.
2. Cutting, crushing and loading in a single operation.
    a. As the SM progresses forward along the run, the cutting drum rotates against the direction of travel. This process cuts the material and allows the drum to crush it against the solid rock still in the seam. This results in minimising fines which increases the recovery of the seam. Appendix 3 illustrates the SM’s working principle.
    b. The material is loaded onto the primary conveyor by the cutting drum and is then transported to the rear of the unit where it is transferred to the discharge conveyor. This conveyor is height-adjustable and slewable, which allows for accurate and efficient discharge of the material.
3. Blasting is avoided, stable surfaces are created.
    a. Wirtgen SMs operate on unblasted material as the cutting drum is able to break bank material. This means that Wirtgen SMs are able to cut overburden and interburden effectively. Furthermore, being able to maintain cutting depth, stable surfaces are created.

4.2.2 *Wirtgen SM4200*

4.2.2.1 Introduction

The Wirtgen SM4200 offers a model specifically designed for both hard rock and soft rock applications, with the soft rock model having a deeper cutting depth. It should be noted that the SM4200 is designed for conveyor loading only and does not allow for windrowing.

4.2.2.2 Model Specifications

Table 11 summarises the model specifications of a Wirtgen SM4200 and Figure 4 provides an illustration of the unit. Dimensions of the unit are displayed in Appendix 4.

Table 11
Wirtgen SM4200 specifications.

Technical Specification	*Units*	*Value*
Maximum cutting width	mm	4200
Maximum cutting depth	Mm	0-830
Drum diameter	Mm	1860
Rated power	kW	1194
Electrical power supply	V	24
Operating speed	m/min	0-20
Travel speed	km/h	0-2.5
Theoretical gradeability	%	20
Maximum cross slope	%	8
Length of discharge conveyor	mm	16 000
Width of discharge conveyor	mm	1800

Source: Wirtgen Group (2016b)

Figure 4. Wirtgen SM4200
(NAC, 2017).

4.3 ADVANTAGES OF SURFACE MINERS

Clout *et al.* (2007), Williams, Mendelawitz, and Castle (2007) and Riley (2017) have all highlighted advantages to SMs and their role across various operations in the mining industry. From their findings, the following positive deductions can be made.

- There is no requirement for drill and blast; thus, reducing the cost and requirement for these intensive processes there are no operational delays that are associated with preparing an area for drilling and then loading and blasting the area before a digger can start mining the area.
- The SM reduces the requirement for primary crushing as the cutting drum breaks and sizes the material and therefore reduces downstream processing costs. This relates primarily to hard rock operations, although Wirtgen Group (2017) has found that SMs

maximise coal recovery by minimising coal fines by the cutting mechanism employed by SMs.

- SMs are a form of a continuous mining method, which represents a more time efficient mining method.
  - Material is excavated and crushed in one operation before loading directly using one of the loading methods. This reduces rehandle of the material and the potential requirement for dozer power to rip the material.
- The changeable cutting depth allows for selective mining, which results in reduced mining dilution and an improved conversion of resource to reserve. This is caused by the adjustable cutting depth that SMs offer.
- Following extraction, a SM leaves a smooth, flat floor. This results in minimal tyre damage for ancillary and production equipment that have reason to traverse on it. This means that the system can be implemented in haul road construction and maintenance. Improvements in road trafficability and a reduction in tyre wear have been documented by Williams, Mendelawitz, and Castle (2007) when a SM is used for this purpose.
- Improved loading quality is achieved through use of a SM – higher truck fill factors due to smaller particle size and better load dispersion caused by the slewing action of the discharge conveyor optimising the weight distribution.
- Production and blending of resource can be achieved directly as faces are exposed.
- Dust and noise pollution events are reduced compared to drilling and blasting. Dust can be reduced further with spraying rigs fitted to the discharge conveyor of the SM.

4.4 Disadvantages of Surface Miners

Operational disadvantages of SMs, documented by Goves (2012), Riley (2017) and Sherrington (2017) from various operations, include the following points.

- Pit dimension drastically effects the mine planning surrounding the implementation of the SM. The SM requires a good area to achieve production rates and reduce the required maintenance on the unit. If a SM is implemented in an inappropriate location, the area is segmented off and is hard to change into a conventional mining area i.e. if an unexpected breakdown occurs, the SM cannot be parked up easily as the mining area would have to be drilled and blasted.

- Due to the manner that the SM cuts material in a decreasing stratigraphy method of mining, combined with the area that is required to optimise productivity of the machine, a coal scheduling problem occurs. Sherrington (2017) noted that the SM allows for constant ROM coal production, albeit a production of one coal type. Whereas, what is required in thin seam coal mines is various blocks within each pit that are on different coal levels to allow for coal scheduling optimisation. Even though the SM is able to produce from a large area, the whole working section is on the same coal level and therefore, coal scheduling becomes problematic.
- The SM requires ancillary equipment; dozers, graders and loaders, to prepare and maintain the working area of the machine to continue production from the SM.
- Higher productivities warrant longer, straight strip lengths with consistent seams and little interburden.
- There is increased dust when cutting hard dry material i.e. sandstone.
    - Pick consumption also increases when cutting this abrasive material.
- SM are slow moving and thus, relocation of the unit requires a long tramming time.

4.5 LOADING METHODS

There are various loading options available when using SMs. Pradhan (2009) discussed the advantages of each of these loading modes and Table 12 contains a summarised version of the findings. Appendix 5 contains illustrations of each of the loading options.

Table 12
Loading methods summary.

Method	*Description*	*Advantages*	*Disadvantages*
Direct	Directly loads material into haul trucks. Can be from the front or rear of the SM and the discharge conveyor can be slewed.	• Inline or side-by-side loading configurations • Minimises the reliance on secondary loaders - reduction in cost	• Depends on the reliability of the truck cycle – loss of production
Windrowing	Material is discharged directly behind the machine without the use of a conveyor	• Does not depend on truck cycle - continuous cutting • Creates formed stockpile for easy loading	• Requires appropriate SM machine • Rehandle – increase in operating cost
Sidecasting	Material is discharged onto the ground creating a stockpile to the side of the SM.	• Does not depend on truck cycle • Continuous cutting • Three adjacent cuts into the same stockpile • Creates formed stockpile for easy loading	• Rehandle • Requires secondary loader – increase in operating cost

Source: Pradhan (2009)

4.6 OPERATING MODES

4.6.1 *Continuous Harvesting*

The SM operates on a level block and continuously cuts in an oval shape (Pradhan, 2009). The block starts with a wide turning radius for the SM and with each full rotation, the turning radius is reduced. Once the radius becomes too tight for continuous movement of the SM, straight runs are made in the middle of the block. The mode requires wide blocks to maintain continuous runs for as long as possible. Appendix 6 illustrates this mode of operation.

4.6.2 *Empty Travel Back*

SM operates in straight runs, moving forward and once it comes to the end of the block or the run is complete, the SM moves backward without cutting to get into position for the next adjacent pass. This operating mode is implemented when the available pit length or pit conditions are not suitable for turning the SM and the time taken to turn around is more than utilising the empty travel back method (Pradhan, 2009). Appendix 6 demonstrates this mode.

4.6.3 *Turn Back*

The turn back method is the most common operating mode utilised at Wild Oats. After making a straight cut of one strip, the cutting drum is raised, and the SM turns back to make an adjacent cut heading in the opposite direction; Figure 5 shows this process. This is the most widely used method of SM operation as it increases production and recovery of the resource (Pradhan, 2009). However, a long pit length and favourable conditions for turning around are required to optimise this mode. At Wild Oats, a minimum of 30 m is required to turn around the SM.

Referring to Figure 5, the blue arrows indicate the movement of the SM when it is cutting, and the red arrows illustrate the SM turning around (without cutting) at the end of each milled strip (this action is replicated at the other end of the strip but is not indicated on Figure 5). As can be seen, the direction of cutting alternates in subsequent cuts. The green and yellow arrows demonstrate the truck path to firstly get aligned to the SM, then to manoeuvre away once filled to allow the next truck to spot and load. As can be seen, the SM can be milling material four cuts (17 m) away from the trucks, before a grader is required to clean the work area, by removing the rills created by the cutting drum. This allows for the discharge conveyor to be positioned directly above the trucks for optimal loading.

Figure 5. Turn back method implemented at Wild Oats.

Wood (1989) discussed an adjunct loading method to the turn back method, wherein the, SM makes cuts as it is turning around. Appendix 6 illustrates these possibilities. However, at Wild Oats, a distinct turnaround area separated from the working area is preferred (see Appendix 7 for a representation of the SM's working area).

5 SURFACE MINERS IN THE INDUSTRY

5.1 APPLICATION OF THE SURFACE MINER

SMs are a heavy-duty version from those used in the construction industry to resurface bitumen roads and have been adapted for the mining industry. Many different operations have implemented SMs throughout the past 20 to 30 years. Advancement in the technology and a commitment to trialling SMs have seen successful implementation across the world. Consequently, SMs are now viable for different commodities, and are incorporated into many company's equipment fleets. Section 5.2 highlights some of these successful applications of SMs throughout a number of case studies.

5.2 CASE STUDIES

5.2.1 *Coal Mining in India*

India is the third largest producer of coal in the world (Wirtgen Group, 2011) and therefore is continuously researching more efficient and innovative technology to continue, and exceed this high production. From a global population of approximately 300 SMs in operation, 105 machines are in productive use in India (Prakash, Murthy and Singh, 2015).

At one of India's coal mines, Gevra, as many as 10 SMs, each with a production rate of 15 000 t/d, have been operating since a reorganisation of coal production and the inherent transition from drill and blast to SMs in 1999 (Wirtgen Group, 2011). SMs are only used to cut coal at Gevra which has a uniaxial compressive strength (UCS) of 30 to 35 MPa (Wirtgen Group, 2011). At Gevra, 80% of the total coal produced is mined using the SM windrowing process. Gevra uses windrowing as it facilitates the identification of the material quality and has been found to be the most productive method at this site (Wirtgen Group, 2011).

Another Indian mine that adopted SM technology is Talabira-I, which is the only coal mine in the world that has not used a single kilogram of explosive since the SM's inception to mine both overburden and coal (Pradhan, Prakash and Thote, 2013). Eight coal seams are workable at Talabira-I and each has varying thickness throughout the mine from 0.7 m to 45 m (including interburden), so that selective mining is required to recover the coal (Pradhan, Prakash and Thote, 2013). The mine has had success utilising SMs, increasing productivity by 30% with proper planning (Dey and Bhattacharyab, 2012), compared to Indian coal mining averages. This increase in recovery has resulted in Talabira-I being a no coal loss mine (Pradhan, Prakash and Thote, 2013).

Performance of SMs operating in Indian open cut coal mines was examined by Prakash, Murthy and Singh (2013). The findings illustrate a relationship between the UCS of the material and the instantaneous cutting rate that can be achieved by different models of SMs operating in Indian coal mines. As UCS increases, the instantaneous cutting rate decreases, resulting in an inverse relationship. Figure 6 shows this relationship and special note should be taken of model 'C' which represents a Wirtgen SM4200 (the same model analysed in this project).

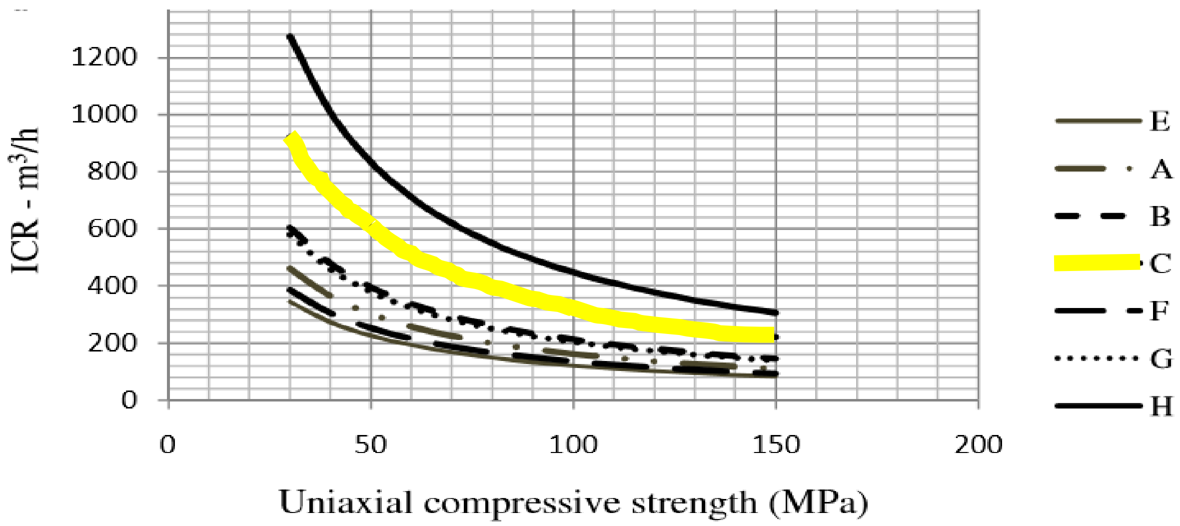

Figure 6. Instantaneous cutting rate of SMs at different UCS (Prakash, Murthy and Singh, 2013).

The authors recommend that from this relationship, a SM should be operated based on its rated specifications and that overworking the machine is not beneficial to production rate. There were also other negative factors, such as increasing diesel fuel and pick consumption and increased vibration and dust. Therefore, extensive testing of the UCS is imperative to understanding the rock properties and thus, the potential of using a SM to cut the material. Furthermore, SM production, with relation to desired particle size, can be optimised by controlling the haulage speed. Figure 7 displays the optimal operating range of a Wirtgen SM4200 for haulage and drum speed.

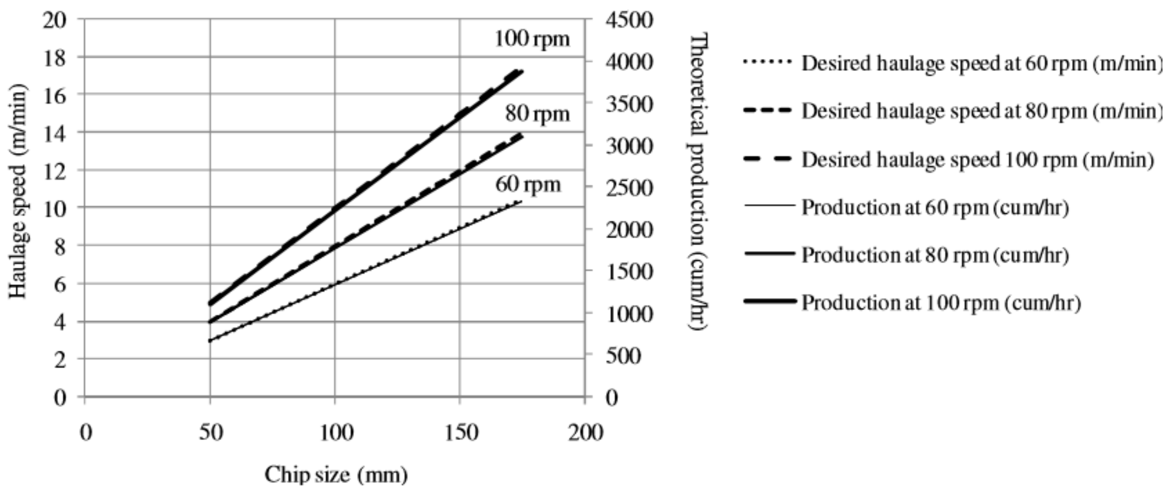

Figure 7. Haulage and drum speed for a production rate and chip size (Wirtgen SM4200) (Prakash, Murthy and Singh, 2013).

India is leading the coal mining industry for primary production from SMs and is a notable example of how introducing pioneering technology and replacing conventional mining methods can be beneficial to all aspects of the mining system. With the success of SMs, Indian mines have begun to produce tailor made SM units to assist in higher production whilst still maintaining the essential SM trait of increased recovery of coal in environmentally sensitive locations (Pradhan, Prakash and Thote, 2013). With the opportunity to operate blast free mines and become more energy efficient, in this carbon emission age, the SM technology offers a scope for development in the years to come.

5.2.2 *Coal Mining in the United States of America*

The U.S.A. is another country that has embraced the SM technology in the coal mining industry. Red Hills is a lignite mine that produces 11 000 t/d to feed a neighbouring power plant. In 2010, a Wirtgen SM4200 was introduced to the site and significantly higher cutting and loading performance has been achieved whilst reducing the fines content from 20% to 8% (Wirtgen Group, 2011). The number of shifts required to maintain a weekly production of 77 000 t has been reduced by 25% since the introduction of the SM. This means an average production rate of above 1000 t/h is constantly achieved by the SM and reaches a maximum of 2800 t/h (Wirtgen Group, 2011). Red Hills opts for the SM to directly load the material into 121 t haul trucks as this offers the highest production rate compared to loading larger sized trucks (Goves, 2012). The 15 MPa lignite coal is deposited in 0.8 to 1.4 m thick seams and requires selective mining to extract the coal and remove the up to 10 m thick interburden (Wirtgen Group, 2011).

The unit is also used to refine haul roads and shape pit drainage which frees up ancillary equipment to be used on other tasks around the mine (Goves, 2012).

Another application, for which SMs have been used is overburden removal in coal mines in West Virginia, U.S.A. Nolan and Kecojevic (2014) examined the mining of shale and sandstone overburden by a SM and calculated the associated cost and strategic production issues, including:

- operating and ownership costs;
- production rate; and
- blasting hazards and material segregation.

Nolan and Kecojevic (2014) conclude that the use of the SM would benefit overburden removal from an environmental standpoint; however, the authors placed higher weightings on the environmental issues, compared to production, when conducting the analysis. The downside of SMs is the higher operating cost compared to conventional methods and the limitation of the machine to cut higher UCS material. A higher UCS material ultimately results in higher pick consumption, which has inherent downtime to change picks and further increases the operating cost of the unit. Overall, Nolan and Kecojevic (2014) deemed SMs to be non-effective in overburden removal and recommended that a SM be trialled in West Virginian mines to confirm the original findings of the paper.

Nolan (2012) researched the use of SMs for coal extraction in coal mines in West Virginia. The findings of this report included:

- lower cost of extraction of bituminous coal compared to conventional methods;
- improved selective mining – increased recovery and decreased dilution;
- an even grade of coal, reducing further processing costs; and
- environmentally friendly mining method.

The cost of extraction was calculated by Nolan (2012) to be 20% lower for SMs when cutting coal due to not requiring secondary crushing compared to rip and stack methods. However, SMs in shale interburden cost approximately 2.5 times more ($/bcm) than rip and stack and cost increases to an additional 6.5 times ($/bcm) for sandstone interburden (Nolan, 2012). Therefore, SMs are not equipped to cut high UCS material and for that reason, for mines with large amounts of interburden, a SM should not be used (Nolan, 2012). Other than this inability to cut hard material, SMs also have lower production compared to conventional methods unless conditions are perfect for SM operations; as Nolan (2012) concluded that the following aspects are required to maintain productivity:

- large working area;
- no water on working area; and
- low UCS material.

5.2.3 *Coal Mining in China*

Shengli Mine has become a reference project in China for environmentally friendly coal mining (Wirtgen Group, 2011). The 15 MPa coal deposit consists of 0.25 m thin coal seams which are extracted utilising selective mining through the windrowing SM method. 97% of the mined material has a particle size smaller than 100 mm and this allows an additional 10% of coal to be loaded for a full truck load (Wirtgen, 2011). These increases in efficiency equate to a production rate of up to 625 t/h (Wirtgen, 2011). At the Shenhua mine, efficiency has increased since the implementation of SMs, due to a 5% decrease in the amount of truck cycles required to transport the targeted production. This reduced the cost of fuel, the number of trucks required and the overall maintenance for the same amount of material moved (Schimm, 2012).

5.2.4 *Coal Mining in Australia*

Wood (1989) investigated the use of a SM at Ebenezer coal mine. Ebenezer was a thin seam, highly selective mining operation with coal seams varying in thickness from 0.05 to 1.3 m and interburden ranging up to 13 m but most commonly less than 2 m. This lends Ebenezer to more rip and stack rather than drill and blast for interburden removal. The implementation of a SM reduced dilution to 6.2%, compared to 10% for conventional mining, meaning that a further 3.8% of coal can be recovered over the life of mine (Wood, 1989). The total coal loss and waste dilution was calculated by Wood to be 0.02 m per working section of the SM. However, this figure does not allow for discrepancies of working around faults, ramps and subcrops (Wood, 1989). Production rates for the SM at Ebenezer reached 540 t/h for coal and 900 t/h for stone, although only one seam was mined in this trial (Wood, 1989). Even so, these results indicated that the Wirtgen SM would be capable to mine a majority of the strata found at Ebenezer.

Mt. Thorley and Howick mines were also investigated by Wood; Table 13 contains a summary of the findings.

Table 13
Mining and haulage cost of different mining method.

Mine	*SM ($/t)*	*Conventional ($/t)*
Mt. Thorley	0.68	1.0
Howick	0.67	1.0

Source: Wood (1989)

As well as reducing the mining and haulage cost per tonne by 30% at Mt. Thorley and Howick, Wood (1989) also reported the following perceived advantages.

- There was a more consistent truck loads due to a reduction in the large oversized fraction of the ROM feed which reduces the amount and size of voids in a truck load:
    - reduction in number of trucks required and a more trafficable pit;
    - reduced operating cost – maintenance and labour; and
    - increased availability.
- Optimal tailoring of picks and drum to allow for desired size distribution and the eliminated secondary crushing.
- It was possible to separate out the clean coal or to blend with other seams for the desired composition.

5.2.5 *Other Reference Projects*

Wirtgen Group (2011) provides examples of different applications where Wirtgen SMs operate globally, this includes:

- iron ore mining in Australia;
- mining limestone in Russia;
- oil shale mining in Estonia;
- salt harvesting in Mexico;
- mining gypsum in the U.S.A;
- phosphate mining in Saudi Arabia;
- mining bauxite in Brazil;
- construction of a port facility in Qatar;
- shale exploitation in Germany;
- Libya limestone mining; and
- quarrying dolomite in Austria.

6 SURFACE MINER AT WILD OATS

6.1 OVERVIEW

Due to a downward pricing of thermal coal in past years, the NHG pursued alternate mining processes to improve mine efficiencies and reduce cost (Volk, 2016). The Wirtgen SM4200 soft rock (coal drum) machine was first introduced at Wild Oats in 2014, as a trial. The SM was first considered as a viable piece of loading equipment due to the advantages in the reduction of ancillary equipment and environmental impacts (Riley, 2017). The SM was compared to conventional rip and stack methods meaning that, ideally, the Wirtgen unit would be able to maintain the production capacity of:

- one CAT 992 wheel loader; and
- two CAT D11 track dozers.

Throughout the trial, financial and production analysis was undertaken to examine the outcomes and to determine whether the SM can solely replace the three conventional machines and therefore have fewer operating units and reduce the overall operating cost.

6.2 TRIAL PHASE

6.2.1 *Overview*

A four-month trial phase provided the data to determine the usefulness of the SM at Wild Oats. The machine operated in Pits 2 and 3 during this trial and was initially used to remove overburden and then for the following three months was used on both coal and interburden. After this trial phase, the SM was introduced as a major loading unit at Wild Oats, based on the successful outcomes and performance during the trial.

6.2.2 *Outcomes*

Throughout the trial phase, the machine productivity improved, which was expected, as operations gained experience in utilising the machine and operators became familiar with the unit. Overall for the trial, the SM recorded (NHG, 2014):

- higher than expected production (bcm/h) when on coal: increase of 8%; and
- less than expected production on waste: decrease of 5%.

However, these numbers include the early stages of implementation and thus, once the machine was acclimatised, the actual production rates were equivalent to the planned production. This high production compared favourably to the rates achieved by conventional equipment; the SM was able to mill and load material 50% quicker than a dozer/loader system.

In seams less than 300 mm thick and when the machine was utilised to map the coal-waste interface, the production rate reduced. Furthermore, when cutting along the interface between interburden and coal, the cutting drum fluctuates in a sine curve manner (illustrated in Figure 8) with fluctuating amplitude of ± 25 mm (Prochnau, Carter and Volk, 2016). The length of period is approximately 6 m with the operator correcting the cutting depth every 3 m.

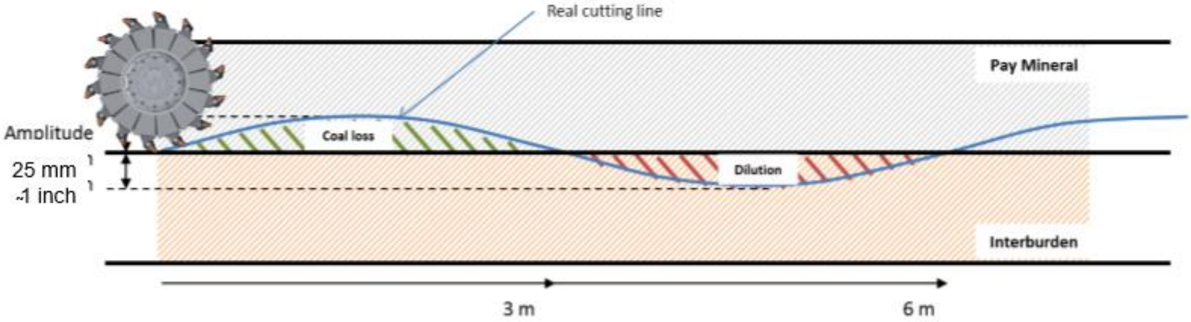

Figure 8. SM loss and dilution model
(Prochnau, Carter and Volk, 2016).

Even though the machine specification states that the Wirtgen SM4200 has a maximum cutting depth of 830 mm (Wirtgen Group, 2016b), it was found during the trial phase that this is reduced to 750 mm when in practice at Wild Oats (NHG, 2014). The minimum cutting depth of 150 mm was found, after which maintaining constant cutting depth becomes problematic and production rate decreases when making cuts less than 300 mm deep.

Optimal strike length of 300 m was determined by NHG (2014) for maximum productivity and an optimal width of block was identified as 200 m, as this width allows for ancillary equipment to operate in the block simultaneously, which is required to maintain the 'tidiness' of the block and clean up areas that the SM is unable to manoeuvre. Therefore, at least two 150 m x 150 m blocks are required to optimise/maintain productivity of the miner.

In the early stages of the trial only 65% of the active area of the block was able to be mined using the SM. Throughout the trial, this increased 90% and was anticipated by NHG (2014) that this 90% recovery rate would remain throughout normal operation. This 90% recovery equates to approximately 30 m wide turnaround area at the end of the SM runs, which can be mined by the SM at a reduced production rate as the empty travel back method must be implemented due to the inherently shorter runs. The soft-walled sides of the runs created by the cutting drum must also be mined using conventional equipment. Appendix 7 contains illustrations of the recovery area and softwalls created by SMs.

Availability of the SM was lower (0.5%) than expected with maintenance cost exceeding the forecasted figure. This was due to initial modifications to the machine to allow higher production at Wild Oats. However, pick consumption and drum maintenance were two of the major components resulting in downtime and fuel consumption was 12.5% higher than expected (NHG, 2014).

The SM produced better particle size with a 10% increase on the distribution of particle size and a 1.4% decrease in fines compared to conventional mining. This was beneficial for both the ROM coal for the CHPP and waste, which was used for road base of haul road construction and rehabilitation areas including the capping of tailings cells.

6.3 JUSTIFICATION

The outcomes of the trial were analysed against KPIs and it was found that the SM performed to a high standard with Prochnau, Carter and Volk (2016) identifying the following benefits of the unit (KPIs of the trial can be found in Appendix 8):

- better coal recovery (less loss and dilution);
- increased productivity;
- unit cost savings;
- decreased wear and better handling of ROM coal at CHPP (cleaner coal, amount of fines and target particle size);
- improved handling of seams that contain siderite intrusions;
- reduced complexity and more efficient mining due to less equipment involved; and
- positive environmental impacts (less noise, carbon emissions, less blasting).

Specifically, Prochnau, Carter and Volk (2016), investigated the expected production rate of the SM and the resulting reduction of the amount of equipment required using the findings of the Wild Oats trial. Figure 9 illustrates that with a Wirtgen SM4200 the expected production rate, when compared to a rip and stack method, increased dramatically. However, the production rate range also increased, which means that the SM is more unreliable than conventional equipment even though it has the potential to improve productivity.

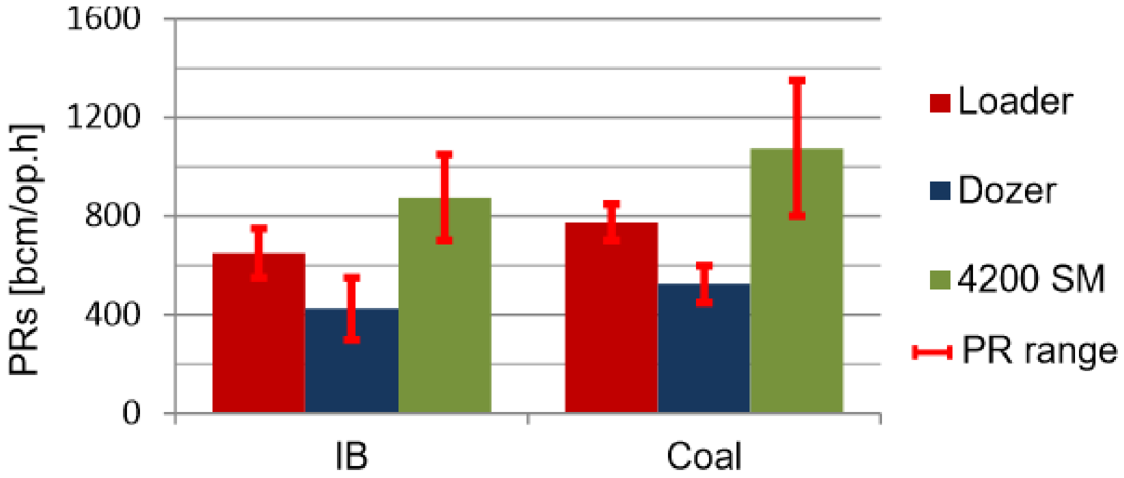

Figure 9. Production rate ranges
(Prochnau, Carter and Volk, 2016).

Similarly, a reduction of approximately 70% of equipment was found when implementing SMs on both interburden and coal. Figure 10 shows that with the incorporation of a SM, the amount of equipment can reduce from 3.5 units to a single SM unit.

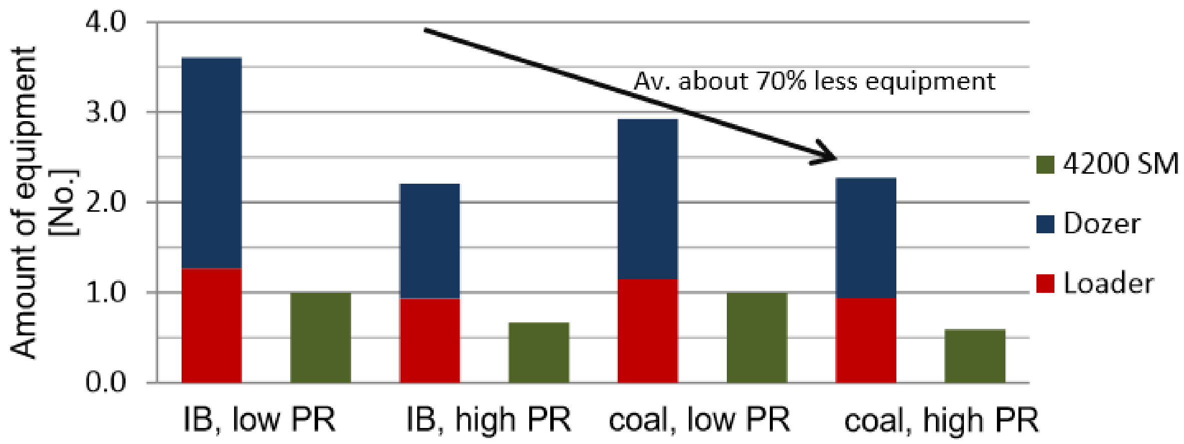

Figure 10. Required equipment amount
(Prochnau, Carter and Volk, 2016).

However, this model did not include the ancillary equipment that is required for the SM to operate safely and efficiently. NHG (2014) reported that the SM requires graders, dozers, loaders and small excavators as it physically cannot mill the entire working area. This includes the turnarounds, edges and maintaining a level area by removing rills created to the side of the cutting drum. 56% of the total equipment time spent in the block is done by the SM with 15% of ancillary equipment required (graders, water truck etc.) to allow the SM to operate safely. The remaining 28% of operating time is done by dozers and loaders to clean up the turnarounds and edges created by the SM. Figure 11, illustrates the operating hours required for the different equipment types.

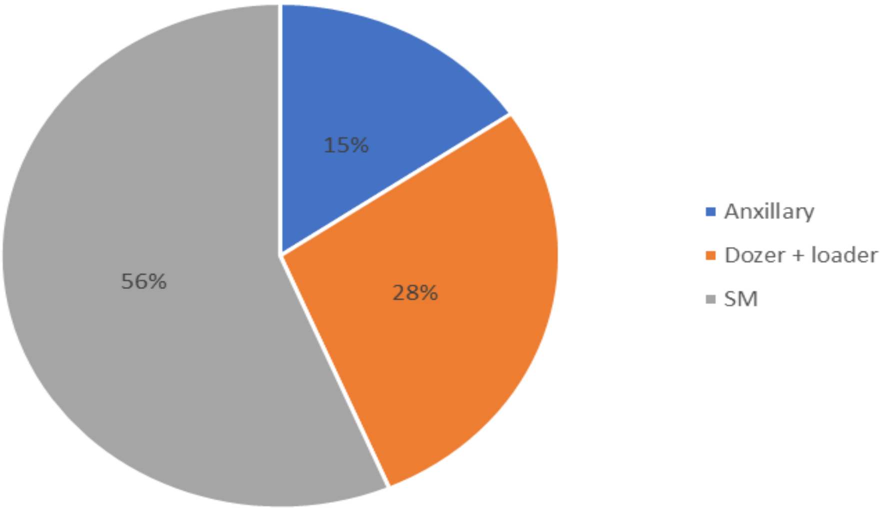

Figure 11. Required operating time per equipment type (NHG, 2014).

NHG (2014) determined that the four-month trial was a success and Wild Oats proceeded to purchase the machine. Further investigation surrounding the maintenance and modification of the unit to achieve the required production rate was required.

7 METHODOLOGY AND DATA ANALYSIS

7.1 OPERATIONAL PRODUCTION DATA

7.1.1 *Data Collection and Content*

The operational production data of the SM at Wild Oats comprised the majority of data collection for analysis. The information was collected over a 2.5 year period and was displayed and recorded based on daily production of the SM. Data was supplied in Microsoft Excel spreadsheets compiled by data entry clerks and administrative staff at Wild Oats. The data from 2017 was taken automatically from a fleet management system (FMS) that automatically recorded tonnages and load counts, whereas, the data from previous years was recorded by shift supervisors. Appendix 9 provides an example of the daily operational production sheet for a month of data. Each operational year was separated and included the following data aspects:

- type of material loaded (including seam/flitch) which was the next point of difference in the data sets;
- date and shift of each load;
- location of operation, including pit, strip and block;
- the number of loads; and
- total production in bcm.

A separate spreadsheet provided the operating hours, including the delays recorded, of the SM in each operating day (Appendix 10). Nominally, six spreadsheets were used in the analysis, however, once combined a broader analysis could occur investigating geotechnical and supervisor comments regarding the work area of the unit.

7.1.2 *Productivity*

The productivity of the SM was calculated using total production (bcm) and milling hours. A pro-rata system was implemented to calculate the number of hours that the SM was milling the distinct types of material. This resulted in hourly production rates (bcm/h) for all the material that was loaded on that specific day. The results were expressed as bcm/h when milling both coal and interburden, as bcm was used by Wild Oats as the general units of production measurement. Applying a conversion factor for the density of coal (to display coal production in tonnes), seemed redundant as this was neither accurate nor required in the analysis.

Production rates were summated and then expressed as an average productivity per month of operation and were then compared to the target production rates applied by the mine using three-monthly scheduling. The performance of the SM was indicative of whether production targets were reached. If the unit failed to reach the production target, investigation occurred into the reasons that affected the production. The performance was displayed as a percentage, actual production over target production.

7.1.3 *Productivity by Material Type*

The material type influences the productivity rate and thus was the main point of interrogation of the data. Productivity was filtered and categorised by material type and then seam number to reorder the data and provide accurate results. As discussed in Section 3.3, there are various types of interburden and coal seams throughout Wild Oats and the recorded seam in the production spreadsheets relies heavily on the SM operator's knowledge of the geology for accurate data entry.

7.1.4 *Productivity by Location*

Working area dictates the operating length and width of the SM which affects the number of turnarounds required to complete a block pass. Using the pit, strip and block location recorded in the production spreadsheets and communicating with the industry professional, a clear picture of where the SM has been implemented throughout its life was generated. Geotechnical and supervisor notes were also used to better understand the issues and benefits of each operating area.

7.1.5 *Operations*

The classification of each activity type was required to calculate the availability, utilisation, job efficiency and effective productive utilisation. The total calendar time was split into two periods: scheduled calendar hours and scheduled losses. From the scheduled calendar hours, the machine could either be available or unavailable with these categories split further as Table 14 illustrates. Basically, the SM, when scheduled to be working, could be classed as working, operational delay or undergoing scheduled or unscheduled maintenance. Appendix 10 contains an example of the raw SM activity data.

Table 14
Categorisation of SM use.

Calendar hours	Scheduled calendar hours	Available hours	Utilised hours	Productive hours	Milling and loading
				Operating delays	Refuelling, operator hot seat changeover and waiting on equipment (ancillary and trucks)
				Non-productive	Tramming
			Reserve		Non-manned and waiting on supervisor
		Unavailable hours	Scheduled maintenance	Preventive	Pick inspection and change outs
				Programmed	Component change outs and overhauls
				Planned	Inspections for faults
			Unscheduled maintenance	Breakdowns	Electrical, hydraulic or other
				Incidents	Operational accidents
			Others non-maintenance		Crib, meetings, noise, training and weather
	Scheduled Losses	SM not scheduled for operation in mine plan			

Source: (Knights, 2016)

Using the summarised machine use (Table 14) the apparent times for each category were inputted and the machine availability, utilisation, job efficiency and effective productive utilisation were calculated. The availability (Equation 1) is defined as the percentage of time the machine is mechanically available for use (Knights, 2016).

$$Availability = \frac{Available\ hours}{Scheduled\ calendar\ hours} \tag{1}$$

The utilisation (Equation 2) demonstrates the amount of the available hours that the machine was able to be used for productive work.

$$Utilisation = \frac{Utilised\ hours}{Available\ hours} \tag{2}$$

Equation 3 calculates the job efficiency using the amount of productive time the machine was actually used (minus operating delays and non-productive operation).

$$Job\ efficiency = \frac{Productive\ hours}{Utilised\ hours} \tag{3}$$

Effective productive utilisation, calculated by Equation 4, is used to demonstrate the actual working time that the machine was used within the scheduled calendar hours.

$$Effective\ productive\ utilisation = \frac{Productive\ hours}{Scheduled\ calendar\ hours} \quad 4)$$

Finally, Equation 5 was used to illustrate the amount of time that the SM was scheduled as the machine has been used selectively and has been parked up when it is not scheduled.

$$Machine\ scheduled\ time = \frac{Scheduled\ calendar\ hours}{Calendar\ hours} \quad 5)$$

7.1.6 *Overall Unit Cost*

Standardised costing for labour (operator and maintenance personnel), consumables (lubrication and picks), machine wear and fuel were used to generate a cost of loading using the SM. The productivity and time data (availability of the SM) was used to develop a cost per bcm of material moved. Appendix 11 contains the assumptions and general costing information that were used.

7.2 INSTANTANEOUS PRODUCTION DATA

7.2.1 *Data Collection and Content*

The instantaneous production data, example in Appendix 12, was collected through a FMS that records production data in real time with every load being timestamped. Using an immediate GPS position, the exact location of the SM machine is recorded along with the type of material being milled and the tonnage of each load being recorded. Furthermore, the loading cycle time per load and the tonnage per individual load was used to calculate the instantaneous production rate and advance rate of the SM.

7.2.2 *Instantaneous Productivity*

Using the cycle time per load and the respective volume of the load (the tonnage is recorded for all material and conversion factors are used to change tonnes to bcm for partings), the production rate can be calculated using Equation 6.

$$Production\ rate = \frac{Volume\ of\ load}{Loading\ cycle\ time} \quad 6)$$

As the SM has a known cutting width and cutting depth, the advance rate of the SM is found by Equation 7.

$$Advance\ rate = \frac{Production\ rate\ (bcm/h)}{Cutting\ width\ \times Cutting\ depth} \quad 7)$$

8 OPERATIONAL PRODUCTION ANALYSIS

8.1 ASSUMPTIONS

The following information regarding the operational production data was assumed:

- the cutting width of the SM is fixed and constant to the machine specifications;
- the cutting depth of the SM is fixed and constant to the machine specifications (although able to be altered, the tonnages/volume of material cut remains the same with the advance rate increasing as cutting depth decreases);
- the horsepower of the SM is fixed and constant when operating;
- target production rates are fixed and based on mine plan; and
- milling seam specified was recorded by operator and not based on geological confirmation.

8.2 PRODUCTION ANALYSIS OF WIRTGEN SM4200

8.2.1 *Introduction*

For the sake of clarity, comprehensive data records will not be provided in this section, however an example of the data used can be found in the respective appendices (Appendix 9, 10 and 12). Furthermore, for confidentiality of the client, a pro-rated approach was used to keep the production rate and associated economics private. It is for this reason that the results in the following sections are shown as a percentage or pro-rated to the target production rate.

8.2.2 *Productivity*

As this project looks at 2.5 years of data, over 700 operational days were incorporated into the productivity analysis. Therefore, as a means of simplification, monthly averages were used to display the average production rate of the SM when milling all material types. Figure 12, contains a graphical representation of the pro-rated data with the constant orange line indicating the target production rate. As can be seen, keeping in mind this monthly average production rate includes milling both interburden and coal, the SM was able to exceed the target production rate on multiple occasions. Not including the month of April 2017 (wherein the SM did not operate due to a scheduling decision), 14 out of the 29 months of operation the SM exceeded the target production rate and by interpreting the negative correlation of the trendline, the average production rate decreases significantly, which indicates:

- the target production rate is too high to be used for both interburden and coal; and
- it is becoming harder for the SM to be scheduled and implemented in appropriate locations to reach the target production rate.

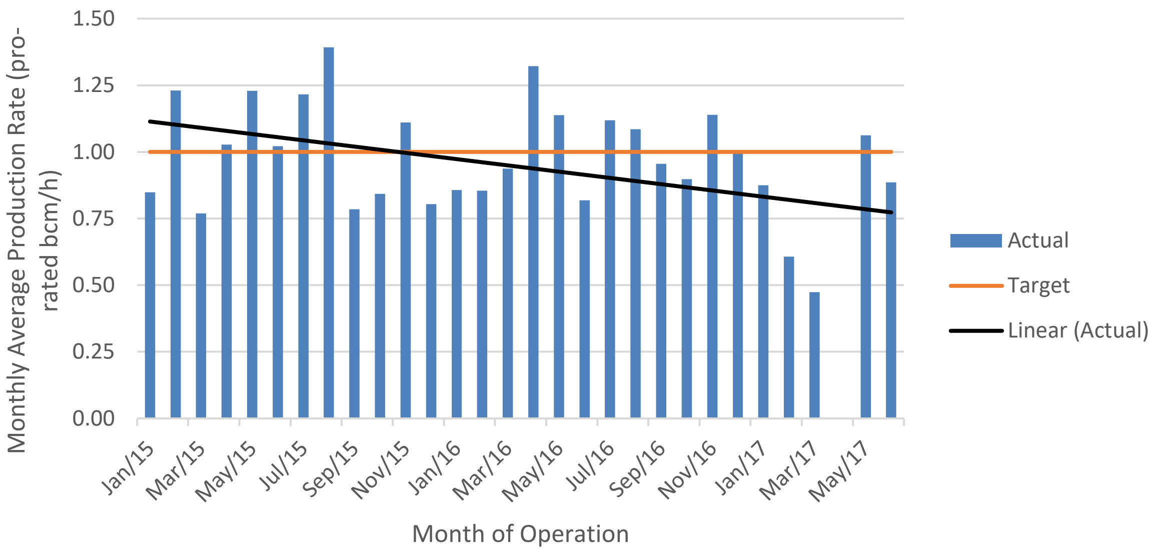

Figure 12. Monthly average production rate of SM milling both interburden and coal.

By taking a holistic view on the data and considering yearly averages, the results provided a similar conclusion. Table 15 contains a summary of the yearly averages displayed as actual production compared to target.

Table 15
Actual SM production compared to target.

Year	*2015*	*2016*	*2017*
Actual production compared to target	+9%	+11%	-33%
Coal to interburden ratio	0.9:1	0.8:1	0.4:1

It is evident that in 2015 and 2016, the SM was used effectively and that the target production rate was accurate and achievable. Understandably, in 2015 and 2016, when the SM was on coal and interburden relatively the same amount of time, the production rate was above target, whereas in 2017, 70% of the time the SM was milling interburden resulting in missing the target production rate by 33%. This shows that the type of material being cut drastically effects the potential for the SM to meet the target production.

8.2.3 *Productivity by Material Type*

8.2.3.1 Introduction

The following sections provide summarised data sets separately for when the SM is milling coal and interburden. The data has been pro-rated and is shown as a percentage (above or below) the target production rate. Therefore, the target rate in Figure 13 and 14 is set to zero meaning that a rate exceeding the target is represented positively along the y axis, whereas a negative y value illustrates the SM not meeting the target production rate by a certain percentage.

8.2.3.2 Coal

Figure 13 illustrates the production rates achieved by the SM when milling the various seams of coal. As the ‘B’ coals are predominately blended together in the mining process due to the interburden being thin and variable, therefore in Figure 13, rather than separating the rates for each of the seams, a bulk mined sequence is used for the B1-6 and B8-C1. It is for this reason that E2-4 and E6-7 are also displayed in this way. The D6 and D7 seams are variant throughout the mine; in Pit 2 the D7 interburden (the parting that separates the D6 and D7 coal seams) is apparent and requires ripping to mine the seams selectively. However, in Pit 4, the D6 and D7 seams are stacked on top of each other with no interburden present, therefore, mining these two seams together is common in this part of the mine.

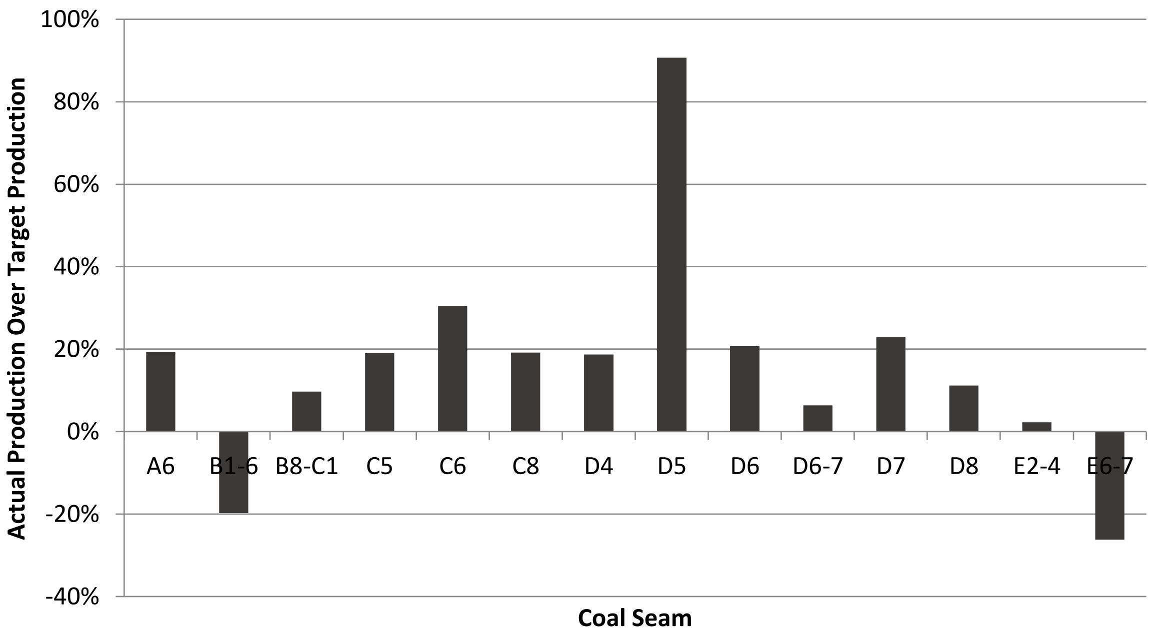

Figure 13. Pro-rated production rate when milling various coal seams.

By analysing Figure 13, it becomes evident that the SM, on average, can achieve 20% higher than target production over many of the mined coal seams. An overall average finds that when the SM is cutting coal a production rate of 16% over target is achieved. The D5 seam is mined at almost double the target production rate of the SM. Wild Oats has recognised this, as the SM has spent 12% of its cutting time on this seam (third highest). The following points outline the reasons for this high production rate.

- The D5 coal seam is consistent throughout the mine.
- The seam is approximately 400 mm which is half the maximum cutting depth determined by Wild Oats. This allows for an adequate advance rate along the block and for a valuable pass to be made.
- As discussed in Section 6.2.2, the SM does not operate effectively when making cuts less than 300 mm; the D5 seam is thicker than this throughout the mine.

Furthermore, the seams that do not reach the production target and those that only slightly achieve target, are the seams that are blended. The bulk mining strategy of mining the thin seams of parting together with the coal does not improve the production of the SM. The reasons for this are listed below.

- The presence of interburden means the SM is cutting through inconsistent material with various strength, hardness and density.
- Increased depth of cutting is required. Instead of selectively mining a full pass at the top seams thickness, the cutting depth is maximised and multiple passes through thin coal seams and partings is completed requiring more force to maintain advancement along the block.
- The parting has a higher density than the coal and therefore when the material is being loaded, the truck will reach the specified maximum tonnage quicker, reducing the loading time. This in turn means more trucks are needed to ensure the SM is never under trucked, this puts more strain on other loader circuits.

Overall, the SM performs well when milling coal and is effective in reaching the current target production rate. From these findings, an increased target production rate could be used to improve mine planning and long-term scheduling of the machine. By raising the target by 10-15% for coal cutting, a better comparison and usage of the machine can be found. By scheduling the SM to cut all ‘C’ and ‘D’ coals throughout the mine, the increased production rate would be reached and optimal usage of the machine would be achieved. There could be a case that the production rate continues the downward trend in the ‘E’ coals, due to the challenges with the pit going deeper, however the SM has not been used on ‘F’ coals so it cannot be determined from the available data.

8.2.3.3 Interburden

Figure 14 displays the production rate results of the SM when milling the separate partings.

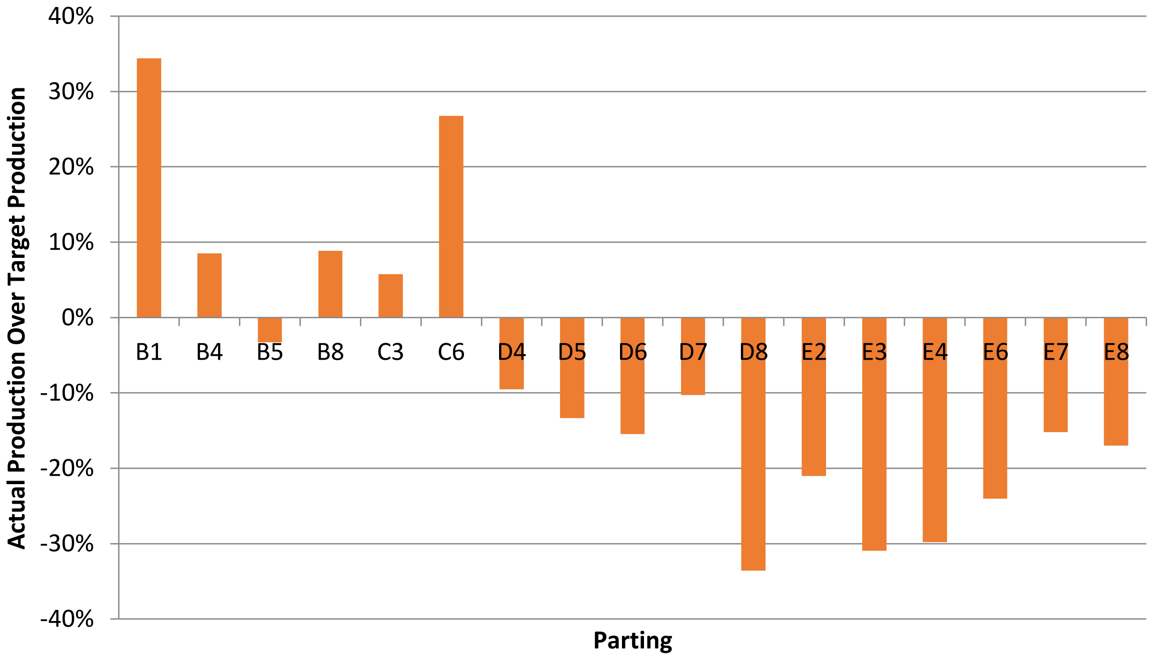

Figure 14. Pro-rated production rate when milling various partings.

Overall, the trend of the interburden production rate was declining as depth increases to the ‘D’ and ‘E’ interburdens. The clear findings from the interburden data, was the turning point at which the SM cannot reach the production target, before reaching the D4 interburden level. It can be determined that prior to the D4 level, the SM is able to meet the target production rate by 115% (on average). B1 and C6 partings are able to be cut at over 120% the target rate due to the following reasons.

- The B1 parting is variable in thickness and is sometimes considered part of the overburden as the first viable coal seam can be the lower ‘B’ or ‘C’ coals.
- Usually a mudstone, the material is similar in properties to the higher coal seams and thus can reach the coal production rates found in Section 8.2.3.2.

- C6 parting is a claystone that is approximately 50 mm thick and is standard throughout the mine. This allows for a consistent approach to be used whenever C6 parting is being mined.

Higher partings in the stratigraphic order offer advantages as these interburdens are closer to the surface:

- the working area is larger compared to pit floor;
- requires less distance for a ramp to reach working level – larger operating area; and
- less water issues – water will flow to the lowest part of the pit.

Once the C8 coal is mined (level directly above the D4 interburden level), the production rate of the SM drops and is only able to achieve (on average) 80% of the target production rate when mining the 'D' and 'E' interburdens. Namely the interburdens that cause the biggest reduction in production rate are the D8 and E3-4 partings which meet 70% of the target rate. The reasons for this are:

- these partings usually require blasting (thick and hard interburdens); and
- interburdens are lower in stratigraphic order – deeper in the pit.

8.2.3.4 Summary

Due to the variance in production rate for both interburden and coal, incorporating these findings into scheduling for the mine would lead to having different target rates dependant on the material being milled. Table 16 contains a summary of the possible target rates.

Table 16
Possible new production target rates.

Target Rate	*Coal*	*Interburden*	
		Above C8 Coal	*Below C8 Coal*
Current	100%	100%	100%
New	113%	113%	80%

Comparing the new possible target rates with the current targets, an increase of 13% for all coal mining and for interburden above the C8 coal level, whereas a reduction in target by 20% for interburden below the C8 level. As this may become complex for scheduling, reducing the target by 10% for all interburden would provide a realistic reflection of actual rates compared to target rates in the mine plan. Altering the target rate would account for:

- a more accurate mine plan with precise material movement for daily, monthly and yearly reporting;
- better scheduling of SM – better understanding of timeframes for material and equipment movement for production purposes; and
- simplified truck movement – less under/over trucking issues.

8.2.4 *Productivity by Location*

8.2.4.1 Operating Length

The operating length effects the amount of time taken to complete a single pass and therefore a longer cutting length increases the time between turnarounds and the number of loads completed in a single run. Figure 15 below illustrates the pro-rated (with average target rate equalling one) productivity of the SM when working in various locations with different cutting lengths. Average productivities the unit achieved whilst working in each area were plotted against the cutting length of the area. As can be seen, for both coal and interburden the production rate improves as cutting length increases and it is clearly beneficial to operate the machine across multiple blocks, increasing the cutting length over 150 m.

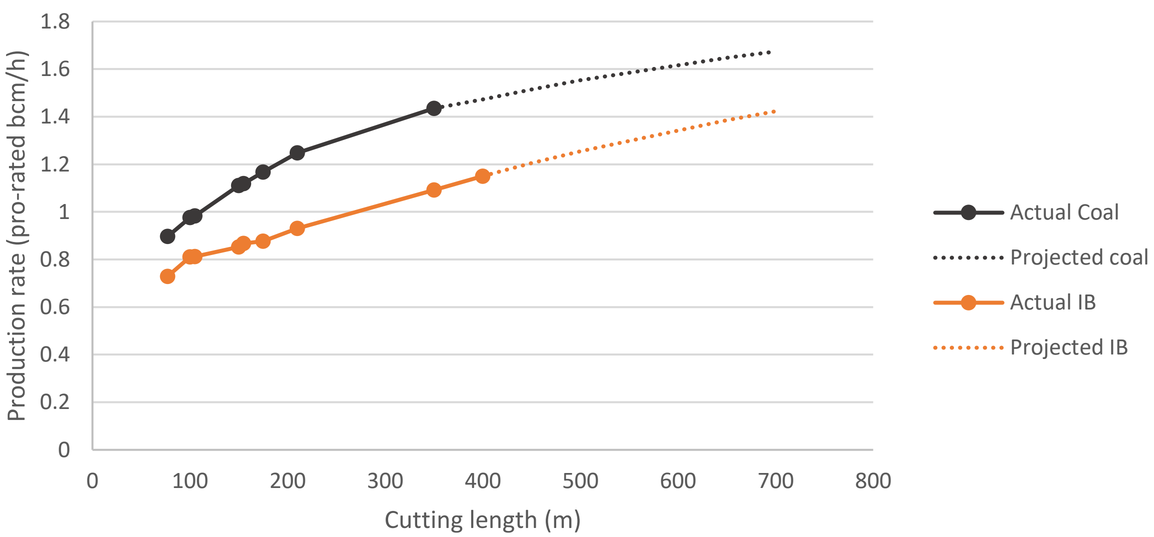

Figure 15. Pro-rated productivity the SM achieved in various strike lengths.

These findings are reinforced by Prochnau's (2015) findings that the theoretical effective production rate is logarithmically proportional to the cutting length. This means that at a point there becomes no benefit of further increasing the cutting length as it provides no major increase in production rate. Prochnau (2015) provided Figure 16 below with the theoretical maximum cutting length that improves production rate to be 700 m; over four normal operating blocks at Wild Oats, which was deemed impractical to implement.

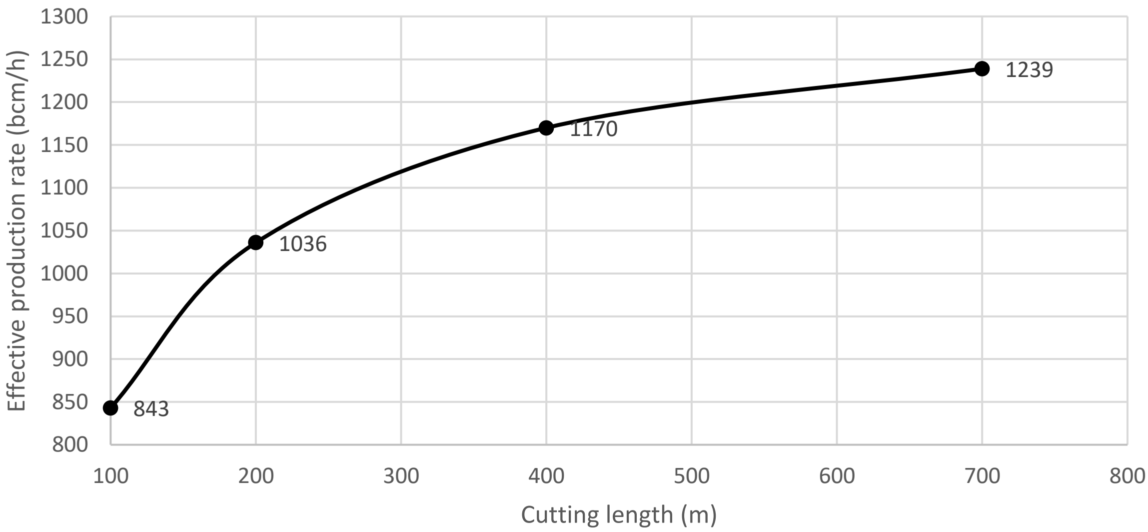

Figure 16. Theoretical effective production rate based on cutting length (Prochnau, 2015).

8.2.4.2 Operating Width

The width of the block has less effect on the production rate as the width is determined more by safe operating procedures of the SM. As the block is first established for operation, the longest dimension is always used as the cutting/strike length for the SM, therefore by default the width is always the smaller dimension of the available block. A block width of 75 m is required to maintain safety requirements and the usual maximum width is 150 m (one standard block width).

8.2.4.3 Operating Area

Incorporating the block length and width, the operating area effects the productivity of the SM in a parabolic manner. For coal blocks, the optimal area is 160 000 m^2 whereas interburden blocks are optimised at 110 000 m^2. As interburden and coal must be mined systematically in the same block, an area of approximately 130 000 m^2 should be used to maximise productivity of the SM through all material types. Figure 17 displays the relationship graphically.

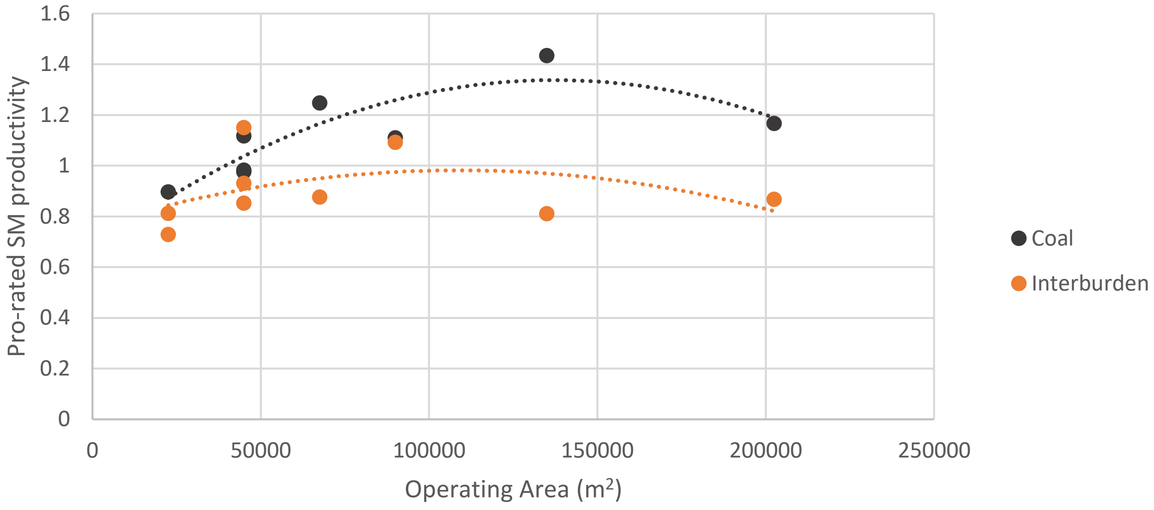

Figure 17. Pro-rated productivity the SM achieved in various operating areas.

Even though the optimal operating area is 130 000 m^2, in practice at Wild Oats six 150 m x 150 m blocks would be required to reach this optimal production area. This is excessive and would not be achieved at Wild Oats due to:

- drill and blast scheduling to shoot overburden limits the amount of consecutive overburden shots in the same area, as the drill is regularly required in interburden shots;
- reduced possibility to blend coal – large area, all on the same coal level – thin seam mining does not benefit this type of coal mining; and
- increased drainage and access problems.

Figure 17 reflects this notion, where most of the SM locations are below 100 000 m^2.

Therefore, due to reducing the number of turnarounds required, a longer strike length has the biggest influence in maximising the production rate. It is recommended that a series of three 150 m x 150 m blocks should be utilised to optimise the SM productivity. Utilising less than this area for the SM will result in inefficiencies caused by the more frequent turnarounds required. An area larger than four blocks also reduces the productivity of the machine which is due to (Riley, 2017):

- harder drainage control in bigger blocks;
- longer distance for trucks to travel through operating blocks;
- more ancillary equipment being required to ‘clean up’ edges and turnarounds; and

- safety standards across larger working area with multiple pieces of equipment being harder to maintain.

8.3 OPERATIONS

8.3.1 *Machine Scheduled Time*

The SM's total calendar time is separated into scheduled calendar hours and scheduled losses. Figure 18 represents one month's division of time into scheduled calendar hours and scheduled losses.

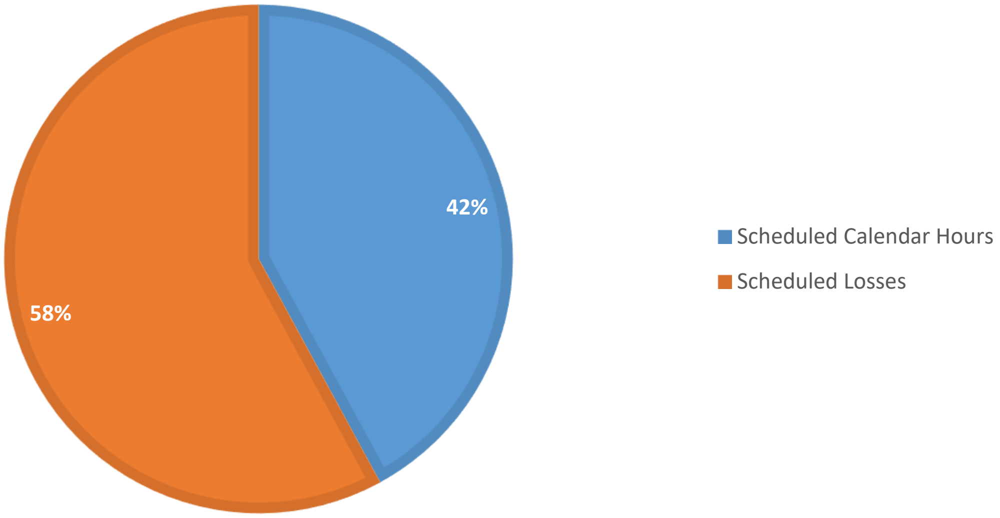

Figure 18. SM scheduled time division.

For the month that was used, the SM was not scheduled to operate for the whole month. This was because for this month, Wild Oats was trialling parking the unit and then using a dozer and loader method to clean up the edges and ends left by the SM and to load out the lower interburden material. Therefore, the scheduled losses include the SM not being scheduled to be used and non-working shifts. The following analysis, uses the scheduled calendar hours rather than the total calendar hours.

8.3.2 *Availability*

Figure 19 shows the availability of the SM for the one-month period.

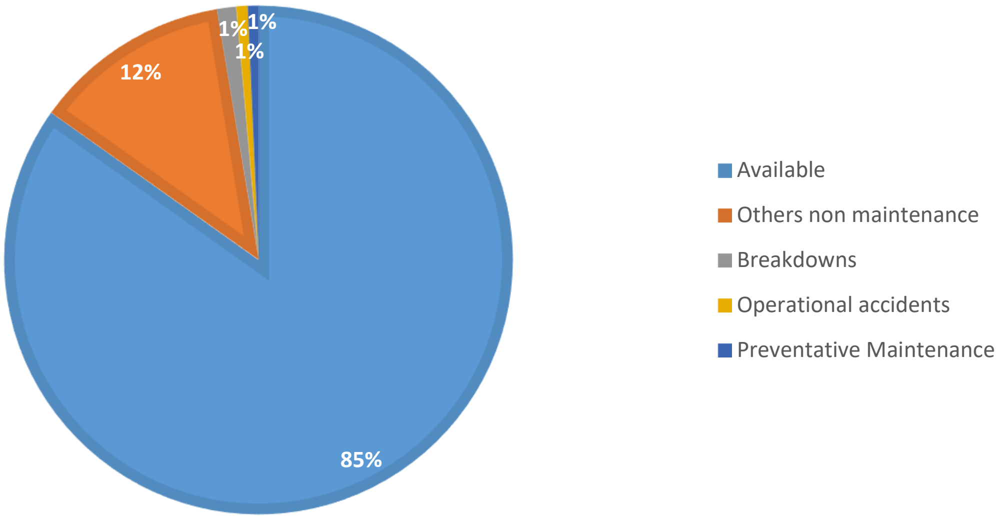

Figure 19. Availability of SM.

Available hours include the following SM tasks:

- harvesting (side casting) and loading;
- refuelling,
- idle time;
- hot seat/operator changeout;
- waiting on ancillary equipment;
- waiting on haul truck; and
- tramming.

All these tasks are considered within regular operation as, even the delays, are required for effective operation of the SM unit. Therefore, the availability of the SM for the one-month period was 85%, the remaining 15% includes:

- non-maintenance:
  - crib;
  - meetings;
  - training; and
  - environmental considerations – noise and weather.
- breakdowns;
- operational accidents; and
- preventative maintenance – pick inspection/changeouts.

8.3.3 *Utilisation*

Below in Figure 20, the utilisation of the SM is displayed as percentages of operating and reserve hours.

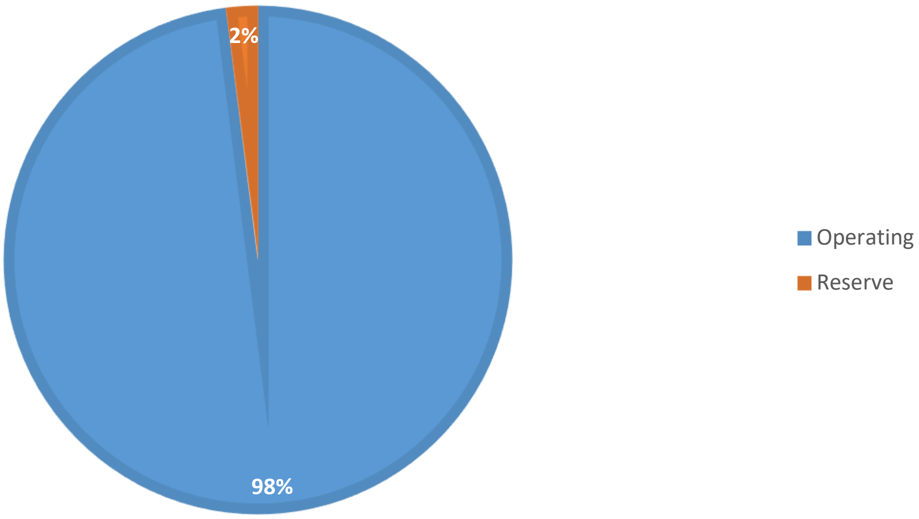

Figure 20. Utilisation of SM.

It is evident from Figure 20, that the SM was able to achieve a high utilisation, 98%, for the month of study. The reserve includes subsidiary delays that are not necessary to operation:

- non-manned SM; and
- waiting on supervisor.

8.3.4 *Job Efficiency*

The job efficiency looks at the distribution of the operating hours and calculated the effective job hours of the SM. Figure 21 displays the results.

The effective job hours incorporate all the time the SM was spent cutting material and this is classified into two categories:

- loading; and
- harvesting (side casting).

From this effective job time, the job efficiency was calculated to be 73% with the remaining 27% being spent on:

- hot seat/operator changeout (operating delay);

- idle time (non-productive);
- non-manned (non-productive)
- refuelling (operating delay);
- waiting on ancillary equipment (operating delay);
- waiting on haul truck (operating delay); and
- tramming (operating delay).

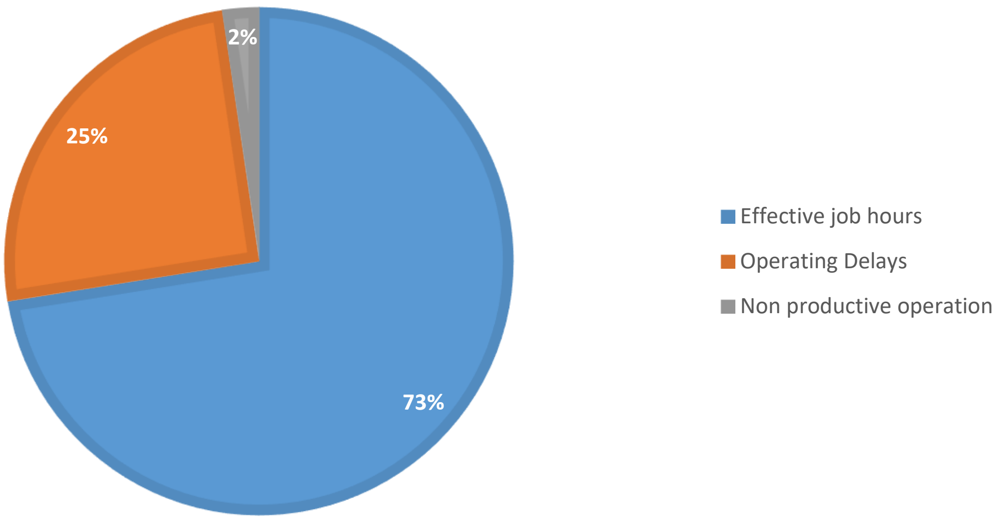

Figure 21. Job efficiency of SM.

A further breakdown of job efficiency for a six-month period can be found in Appendix 13 wherein job efficiency reduced to 60% with idle time constituting 17% of utilised time.

It should be noted that waiting on haul truck, while only a 3.2% of total scheduled calendar time in the month of study, was deemed a key success factor for the SM to reach production targets. This is because, like all load out units, waiting for haul trucks is loss time of production; however, as the SM mining method is a continuous system, the SM is unable to advance whilst the conveyor is not loading. Unlike an excavator which is able to rake material to fill another bucket, the SM must cease cutting material and advancing. Under trucking was visible when analysing long-term averages where waiting on haul trucks increased to approximately 10% of all operating delays.

8.3.5 *Effective Productive Utilisation*

Using the job efficiency, the effective productive utilisation is a factor of effective job time compared to the scheduled calendar time. For the month in question, the effective productive utilisation was 60%. However, incorporating the total calendar time, rather than the scheduled calendar time, the SM was being used for loading and harvesting for 25% of the month. This is a more inclusive figure, as having the unit parked for extended periods of time, the loss of production and thus capital loss of parking a major unit is apparent. Even though parking the unit allows maintenance to refine the machine to reduce breakdowns once the SM is operating again, which reduces the operating cost.

Using the SM to only cut material for 25% of the month, improves availability and utilisation, but this puts more stress on other operating equipment to meet production requirements and thus a decrease in availability and utilisation of other units was apparent.

8.4 LOADING OPERATING COST

8.4.1 *Assumptions*

Appendix 11 contains the values that were used for the economic analysis. The following assumptions were made:

- SM cutting tool consumption – 0.4 pieces per hour for coal and 0.6 pieces per hour when cutting interburden (Prochnau, 2015); and
- availability of 85% when cutting coal and due to the increased breakdowns and pick changeouts, the availability when cutting interburden was decreased to 72% (Prochnau, 2015).

8.4.2 *Analysis*

Economic efficiency is a major aspect of the successful implementation of integrating a new piece of equipment to a mining fleet. The following graphs analyse the cost of production per seam of coal or parting using the real productivity averages found in Section 8.2.3.4. Overall, it was found that the SM costs 32% less when cutting coal. This cost is solely related to the SM and is not a comprehensive mining cost, rather a figure for the cost to load the material into the haul trucks (exclusive of haulage cost).

Figure 22 displays a pro-rated unit cost (converted to $/bcm and then pro-rated to equate the target production rate to $1/bcm) of the SM when milling coal.

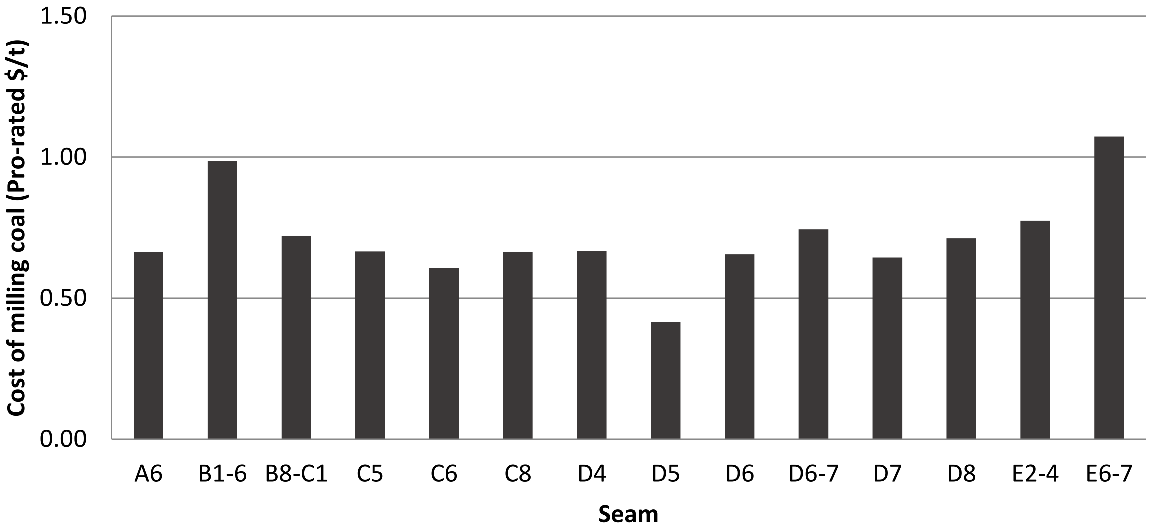

Figure 22. Cost of milling coal.

As can be seen the SM pro-rated cost stays constant at $0.75/t ($0.5/bcm), which when compared to the cost of milling interburden, Figure 23, is significantly less as the interburden pro-rated cost is approximately $0.75/bcm.

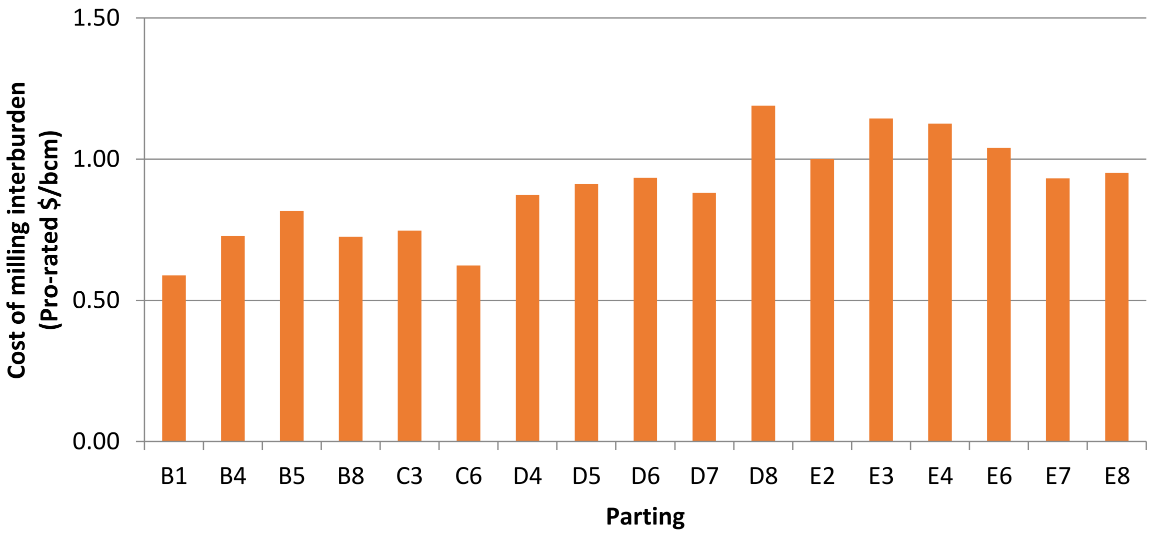

Figure 23. Cost of milling interburden.

The highest costing partings to mill are the lower interburdens (D8 to E8) whereas the D5 coal seam recorded a production cost 70% cheaper. The coal seams that recorded higher costs are those that implement multi-ply mining and blending practices; these are also the seams that record low production rate. Therefore, it was deduced that the factor that has the largest impact on milling cost was the achievable production rate.

9 COMPARISON TO CONVENTIONAL MINING

9.1 INTRODUCTION

As stated in Section 6.1, the SM was purchased to be utilised as a major loading unit and to replace the requirement of a loader and two dozers; the following section explores this comparison using productivity and cost as defining factors. Averages for the conventional mining equipment (one loader and two dozers) production and operating cost were used as analysing conventional mining equipment data was deemed out of scope for this project.

9.2 PRODUCTIVITY COMPARISON

The first comparison that was made was the different preparation of the mining area required; for a SM block, a one-week timeframe for preparation was assumed whilst the conventional option requires three weeks before major loading can begin. This is because for loaders and dozers to work efficiently, blasting is required. Three weeks was allowed for preparing the area before drilling and then loading and blasting the shot. Therefore, the SM can start milling, on average, two weeks prior to conventional mining.

As conventional mining requires more equipment the production rate is approximately double the SM's rate. Figure 24 illustrates the production rate comparison, on a weekly basis, of the two different mining techniques. As can be seen, the SM maintains a constant production rate after the first week of block preparation whilst using conventional methods increases the preparation time but increases the production rate once mining begins. The point where both methods are equal, is 5.2 weeks. This is when total production in the mining block is the same for either option. At this point, using the standard block size of 150 x 150 m, the turning point where conventional mining overtakes the SM is for material approximately 8.5 m thick. This means that for areas where optimal material (coal and high interburden) is less than 8.5 m thick the SM should be used as the drill and blast process requires too long to prepare the area for the loader. If more than 8.5 m of material is required to be cut, it is more time effective to blast the interburden than utilise the SM.

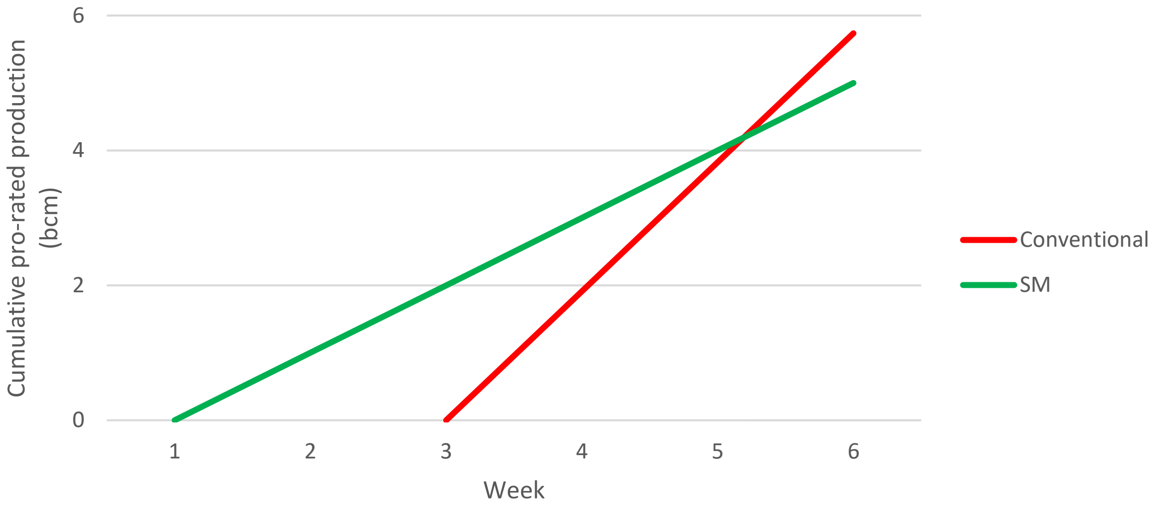

Figure 24. Comparison of productivity of mining modes.

9.3 Economic Comparison

9.3.1 *Overview*

Prochnau (2015) researched the cost of conventional mining at Wild Oats and the values that were found were used for the economic comparison as operation data from the loaders and dozers was not available for this project and analysis was deemed out of scope for this project. Even so, the values calculated by Prochnau (2015) were developed from production data in 2015 at Wild Oats and therefore are accurate for economic comparison. The values were pro-rated, similarly to the economic analysis in Section 8.4 (pro-rated to $1/bcm equalling the cost to mine at the target rate) and were separated into coal and interburden loading cost.

9.3.2 *Operating cost*

Both coal and interburden were separated into low and high categories with ‘high’ regarding to the seams/partings closer to the surface – A, B and C seams and ‘low’ referring to D and E seams/partings. Figure 25 compares the loading cost of conventional and SM methods with the following points deduced from the relationships illustrated.

- For both conventional mining and the SM, coal is milled at a cheaper cost than interburden.
- Low interburden costs the most to mine, due to hardness and thickness of partings, with the conventional system costing two times more than the SM.

- Overall the SM is 37% cheaper in overall unit cost of the loading stage.

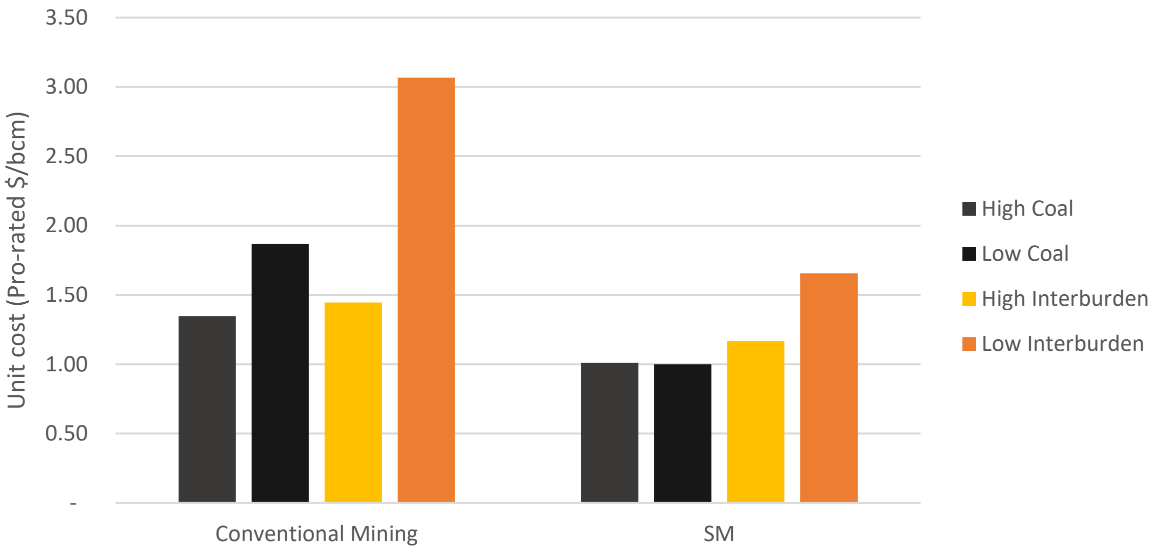

Figure 25. Overall loading unit cost comparison.

This analysis includes the cost of operation for the main loading units and for the low interburden mining using conventional equipment, the cost of drilling and blasting was added. Furthermore, the use of ancillary equipment in each of the working areas were added, namely for the SM this includes:

- graders, dozers and water trucks to maintain safe operating areas for trucks; and
- small excavators and loaders to clean-up edges and turnaround areas to maintain high productivity of the SM.

As can be seen from Figure 25, the mining of low interburden becomes 55% cheaper when the SM is used compared to conventional equipment due to the cost of blasting.

10 INSTANTANEOUS PRODUCTION ANALYSIS

10.1 INTRODUCTION

Instantaneous data was analysed to provide a measure of the SM's potential production rate without delays already incorporated in the data. A one-month period was used as a test period of the instantaneous production rate analysis with the SM milling both interburden and coal within this time. Due to the immense amount of data available, truck load data from one production day was used to provide an understanding of the influence that turnarounds had on the instantaneous production rate. As the tonnage of load and loading time was known, the instantaneous production rate was calculated using Equation 8.

$$Instaneous\ production\ rate = \frac{Load\ tonnage}{Load\ loading\ time} \quad 8)$$

This data was then pro-rated using the target production rate, thus an instantaneous production rate of one equals the average target production rate.

10.2 ASSUMPTIONS

The following information was assumed regarding the instantaneous production data:

- the cutting width of the machine was fixed and constant for each milled strip;
- the cutting depth of the machine was fixed and constant for each milled strip;
- the horsepower of the SM is fixed and constant when operating;
- target production rates are fixed and based on mine plan;
- density of material was constant for coal and interburden respectively;
- the load tonnages recorded by the FMS were accurate to 0.1 t; and
- the load times recorded by the FMS were accurate to 0.5 s.

10.3 INSTANTANEOUS PRODUCTION BY MATERIAL TYPE

10.3.1 *Overview*

Using June 2017 as the month of study, for each load (interburden and coal) the production rate was calculated using Equation 8 and then plotted onto Figure 26. Over the month the SM starting with cutting coal and then interburden. It was then parked for a period (12/06/17 to

21/06/17) as the working area was cleaned up and a hard interburden area was mined using conventional methods. The SM started to mine coal again and then interburden as the pit progressed down.

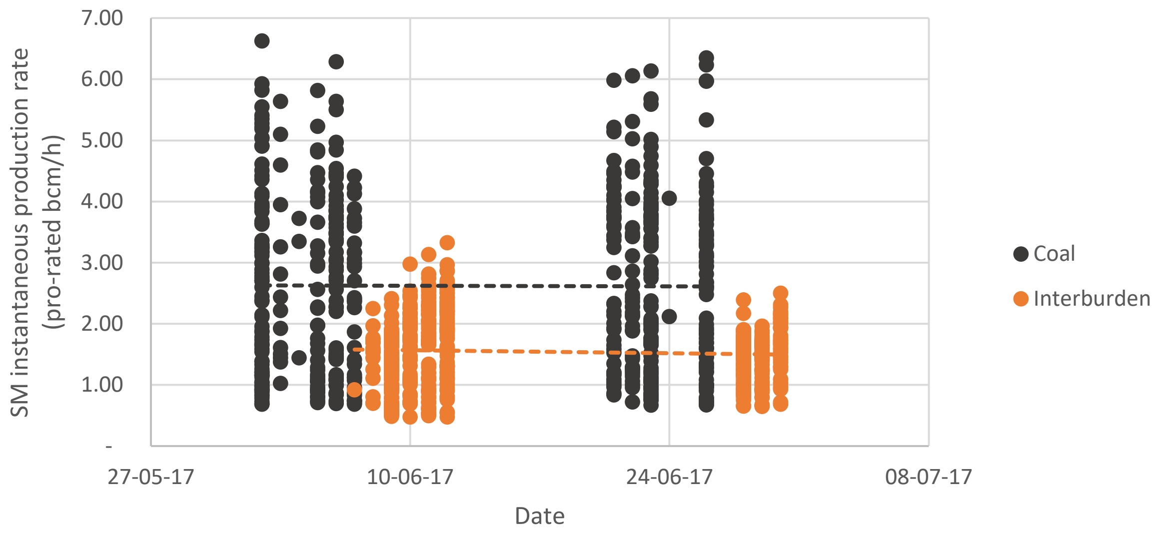

Figure 26. Instantaneous production rate over a one-month period.

With every truck load being recorded, a smaller test period was required to understand the impact of delays on the production rate of the SM.

10.3.2 *Coal*

Figure 27 contains the production rate of 50 loads completed in one day of production. The pro-rated data outlines that the SM was able to mill at 8.5 times the target production rate and has an average instantaneous production rate of 4.2 times more than the target production rate. This shows that when the SM is milling coal, it is highly effective, but the numerous delays reduces the target rate. Furthermore, as seen in Figure 27, the pro-rated data oscillates between 6 and 1. This can be explained by the SM requiring to turnaround; the loads above three are completed when the SM was operating in straight runs and hence each truck is loaded without significant delay. Whereas, the ‘red’ loads under a pro-rated production rate of three, are loads that are slowed down by the reduced strike length at the end of each run and are affected by the time taken for the SM to complete a turnaround.

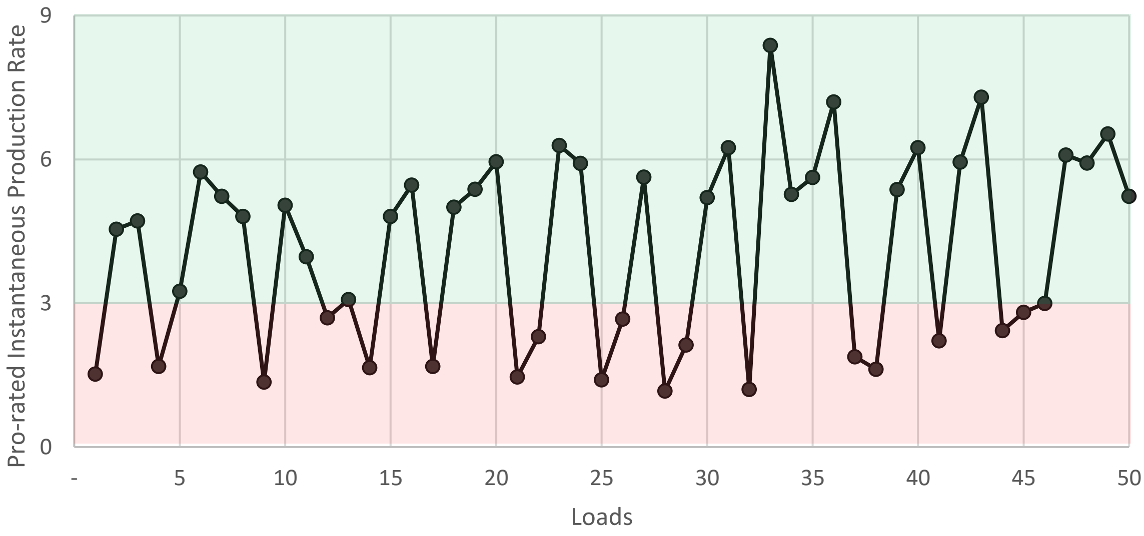

Figure 27. Instantaneous production rate for the SM milling coal.

10.3.3 *Interburden*

Similar to the coal analysis, 47 interburden loads, from the same mining area, were used for the interburden study. However, as Figure 28 illustrates, the range of data is not as severe as the coal analysis. The SM is able to mill a maximum of 4.7 times more than the average target rate with the average instantaneous rate increasing to 3.1 times more than target. The turnaround loads are also evident in the interburden data and seem to affect the cutting rate similar to cutting coal.

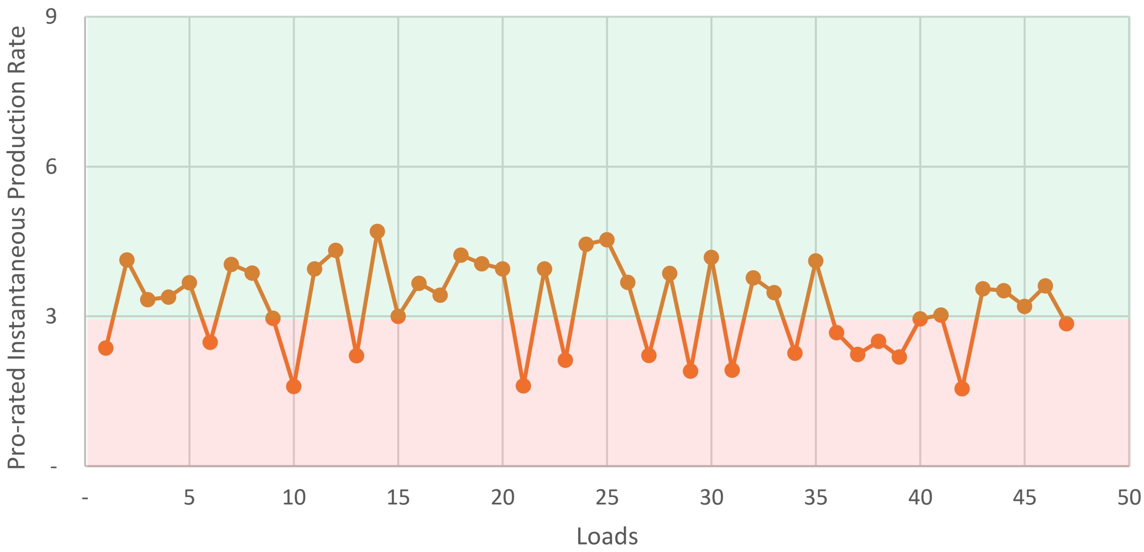

Figure 28. Instantaneous production rate for the SM milling interburden.

10.3.4 *Summary*

Table 17 contains a summary of the instantaneous production rate analysis.

Table 17
Summary of instantaneous production rate results.

Result	*Coal*	*Interburden*
Minimum instantaneous production rate (pro-rated)	1.2	1.6
Average instantaneous production rate (pro-rated)	**4.2**	**3.1**
Maximum instantaneous production rate (pro-rated)	8.4	4.7
Advance rate (m/min)	16.5	12

Overall, the SM when milling coal and interburden is effective with an average advance rate of 16.5 m/min and 12 m/min respectively. Pro-rated production rates of 4.2 for milling coal and 3.1 for cutting interburden were achieved. This information was then used to investigate the use of side casting as a loading method which better utilises the SM potential to reach instantaneous cutting rates rather than the average productivity data which incorporates delays. Windrowing was not investigated due to (as mentioned in Section 4.2.2.1) the Wirtgen SM4200 unit being unable to perform this type of loading.

10.4 SIDE CASTING

10.4.1 *Assumptions*

As Wild Oats does not implement side casting, the following assumptions were made to complete the analysis:

- a loader can operate in the same working area as the SM;
- the reduced instantaneous production rates are accurate for all coal seams and partings;
  - the varying hardness of different interburdens does not affect the instantaneous production rate drastically.
- the SM can side cast the material into a loosely packed, straight and neat windrow to allow for the loader to load the material into trucks without assistance from other ancillary equipment; and
- manipulating the discharge conveyor to cast the material into straight windrows does not decrease the production rate below the reduced instantaneous production rate.

10.4.2 *Productivity*

As side casting is independent of trucks, the instantaneous production results provide a more accurate result of the potential to utilise this method. In saying this, side casting does require ancillary equipment, turnarounds and operator delays; thus, a reduced average instantaneous production rate should be used for the most accurate calculation method. Table 18 summarises the values that were used for the analysis. The recommended target production rates were gained from Section 8.2.3.4 from the productivity by material type analysis and were used as the bench mark for the side casting options (as Section 10.3.4 discovered that these figures are more accurate than the current target).

Table 18
SM side casting parameters.

Parameter	*Coal*	*Interburden*
Target production rate (pro-rated)	1	1
Recommended target production rate (pro-rated)	**1.1**	**0.8**
SM side casting production rate (pro-rated)	**3**	**2**
Loader production rate (pro-rated)	0.8	0.8
SM advance rate (m/min)	12	8

A standard block size and maximum cutting depth of 750 mm was used to provide a timeframe on the length of time required to complete one flitch across a mining block. Therefore, the analysis included the mining of 16 875 bcm of material. There are two side casting options.

1. Parked option – the SM mills and side casts the entire flitch before a loader enters the area to begin rehandling the material and loading into trucks. When the loader is operating in the block the SM would be parked and likewise for the loader when the SM is operating.
2. Continuous milling option – the SM harvests a section of the block (2880 m of milled material: half the block, was assumed) before a loader begins to rehandle the milled material. This allows for both machines to continuously operate. This is an idealistic view on this loading technique as every operating area would be different and may not allow for both the SM and a loader to operate safely.

For the two options regarding side casting, the required total material movement is double that of direct loading due to the associated 100% rehandle of the material using a loader once the material is milled. Figure 29 illustrates the coal movement by different loading options. As can be seen, the side casting method that allows for constant milling (indicated by the ‘red’ line) completes the flitch more time efficiently than the parked option ('brown' line). However, both side casting options are much slower than using the conventional direct loading approach; 33% longer for continuous milling option and 66% longer for the parked technique.

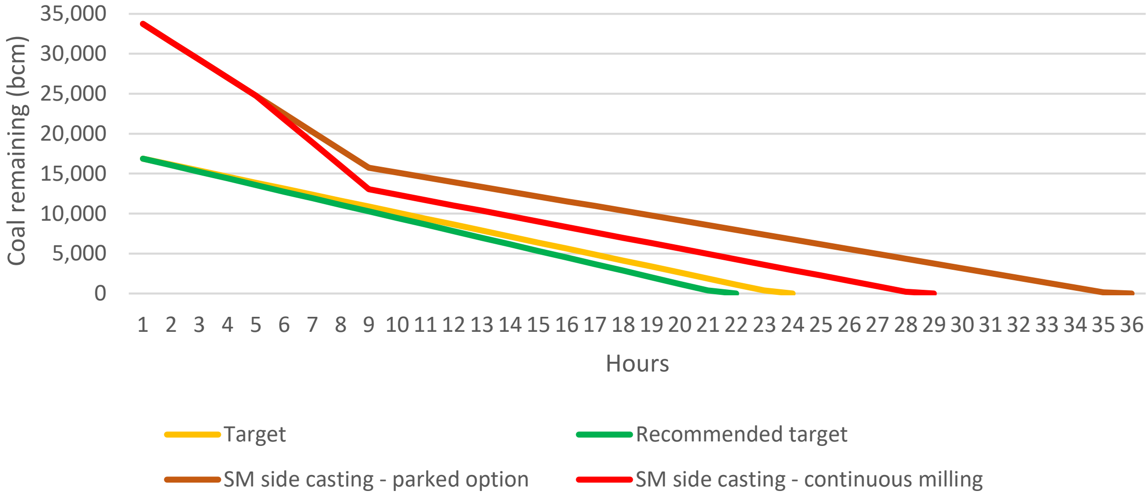

Figure 29. Time taken to mine a coal flitch using different loading modes.

Comparable results were found when comparing cutting interburden with the side casting options being less time effective than direct loading. However, as the recommended target production rate is less than the current target, the side casting option of continuous milling is more advantageous than when milling coal as it only takes 7% longer than the recommended target option. The parked option of side casting takes 30% longer than the recommended target option. Figure 30 below illustrates the time taken for each of the loading modes.

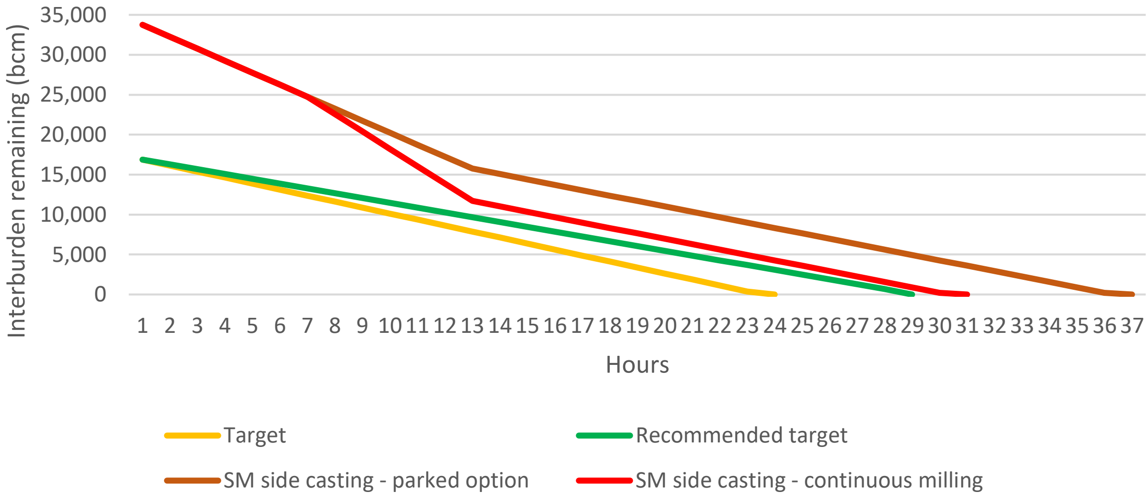

Figure 30. Time taken to mine an interburden flitch using different loading modes.

From these findings, it was deduced that due to the necessary rehandle component, the side casting loading method is not time efficient and the benefit of utilising the SM to its maximum efficiency is lost once a loader (with a lower production rate than the SM) begins loading. However, the correct usage of the SM side casting method would be beneficial. Listed below are some scenarios where side casting could be implemented:

- at the end of runs where strike length is limited;
- in areas where access is tight to allow effective SM turnarounds with trucks running on the same surface;
- topsoil stripping; and
- when under trucked – relocate trucks to major loading equipment (excavators and coal loaders) and allow the SM to side cast material for a period of time until trucks/loader is available.

11 SOCIAL AND ENVIRONMENTAL ASPECTS

11.1 HEALTH AND SAFETY

QMS (2014) provides operator anecdotal reports that put forward the notion that the SM's operator ergonomics and health risk is lower than loaders and dozers perceived by the workers operating the equipment. These accounts were reinforced by a whole of body vibration study conducted by NHG (2014) which provides scientific data that the SM has a lower health risk rating when compared to conventional coal and interburden mining equipment. Table 19 displays the risk rating (see Section 2.9 for further detail on risk assessment) for the health ratings of the various pieces of equipment.

Table 19
Safety and health analysis.

Equipment	*Mining Activity*	*Vibration Level*	*Health Risk Rating*
Wirtgen SM4200	*Continuous surface mining*	*Low*	*Low*
Loader	*Loading broken rock*	*Moderate*	*Moderate*
Dozer	*Ripping and pushing interburden*	*Moderate*	*Moderate*
Dozer	*Ripping and pushing coal*	*Moderate*	*High*

Source: NHG (2014) & QMS (2014)

As can be seen, the Wirtgen SM unit has a low vibration level, due to the milling mechanism of the SM being less 'jerky' compared to the ripping action employed by dozers (QMS, 2014). The overall health risk also results in a rating of low, due to the SM traversing on flat working areas and is not required to push off or mill close to edges of the working bench.

Safe and productive operation of mining equipment requires twisting in the seat to see the work area. This constant twisting in the seat can cause muscle tears or strains. Figure 31 displays the twisting head radius for a dozer and SM operators separately. As can be seen, the dozer operator requires to turn more than 180° to make the working area visible. This compared to the SM which only requires a 90° twisting radius. This is because, as seen in Appendix 14, the SM operator has a good view over the work area without the need to twist their head excessively. With the assistance of display monitors (linked to strategically placed cameras) the operator is able to see the whole work area easily (Prochnau, 2015).

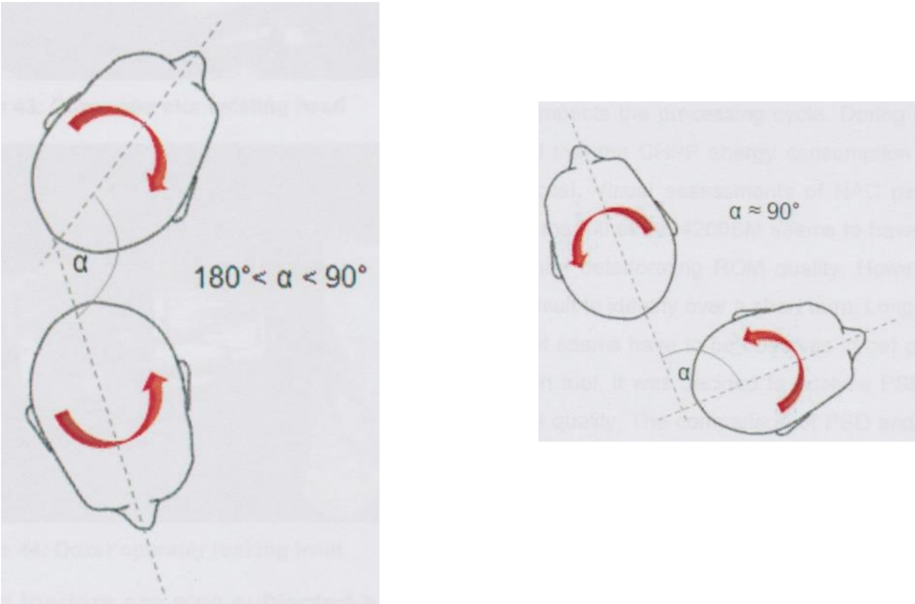

Figure 31. Head twisting radius for dozer (left) and SM (right) (Prochnau, 2015).

11.2 ENVIRONMENT

11.2.1 *Dust*

The SM is fitted with a 10 000 L water tank and pumping system that is able to discharge water through sprays positioned on the milling drum and secondary conveyor. The amount of dust produced by the machine is variable and hard to predict on a long-term basis as it is altered by;

- weather conditions;
- milling material (type and location including depth in the pit);
- milling of windrow (broken ground); and
- ancillary equipment (last pass of water truck/grader)

Overall, the SM does not produce significantly more or less dust than a large load out unit (excavator), which is considered by Wild Oats to not be a 'large amount' (NHG, 2014).

11.2.2 *Noise*

The SM has been fitted with sound attenuation measures which reduce the sound power level to approximately 3 dB lower than that of an unmodified Hitachi 5500 excavator. Similar to dust, noise is heavily influenced by environmental conditions and location of the unit. The benefit of being lower in the pit (mining the lower seams and not overburden material) is that the SM (and trucks) are protected by the cut which lowers the influence of the noise produced by the unit.

11.2.3 *Blasting Events*

As SM mining method does not require the material to be shot prior to the machine mining the area, the intense pressure on blasting is reduced. As Wild Oats is in an environmentally sensitive area, prone to unfavourable blasting conditions, this reduction in blasting events is beneficial. This is true not only for production requirements (less blasts required) but a reduction in the amount of blast events is environmentally favourable. This is because it is less likely that an environmental breach will occur. Listed below are environmental conditions that are beneficial to SM over blasting:

- less vibration;
- less dust events;
- no air overpressure (noise) events; and
- no fume events caused by blasting.

12 CONCLUSION

12.1 PROJECT FINDINGS

This research project was conducted to analyse the operation of a Wirtgen SM4200 and compare these results with a conventional mining process. For the analysis, the mining methods were outlined with the SM direct loading being compared to two dozers and one loader rip and stack method.

Initially, information on Wild Oats and the mining methods was outlined. Research was required to identify general aspects of the SM and outline the potential advantages and limitations of its use at Wild Oats. SM use in the coal mining industry was researched to outline the various success and drawbacks that coal mines within India, U.S.A, China and Australia have experienced with SMs. The data collection and analysis methodology was then outlined for both the production data and the real-time instantaneous production data.

By examining monthly averages of each of the months the unit has been in production, it was deduced that the target production rate was too high to be used for both interburden and coal and it was becoming harder for the SM to be scheduled and implemented in appropriate locations to reach the current target production rate. However, by considering yearly averages it was concluded that in 2015 and 2016, when the SM was cutting both coal and interburden for the same amount of time, the actual production had a 10% improvement on target, but in 2017, when interburden was being milled 70% more often than coal the actual production was 33% down on target.

Due to the variance in production rate, for both interburden and coal, it was concluded that altering the target is required to improve mine scheduling of the SM unit for the future. An increased target production rate for coal of 13% and a reduced target for interburden of 10% was proposed. This reduction in production rate is due to these partings requiring blasting (thick and hard material) and the working area reduced as the pit progresses deeper, which increases potential to have water issues.

The practical cutting length (length of operating block) was deduced to be 450 m in practice with an optimal operating area is 130 000 m^2. Considering the width of block had negligible effect on the productivity of the SM, this calculated area was deemed inefficient and it was recommended that a series of three 150 m x 150 m blocks should be utilised to optimise the SM productivity. Utilising less than this area for the SM will result in inefficiencies caused by the more frequent turnarounds required. An area larger than three blocks results in harder drainage control in bigger blocks and requires more ancillary equipment to ‘clean up’ edges and turnarounds.

The effective productive utilisation was 60% for the SM with the main delays being non-maintenance (crib and training), environmental considerations (noise and weather), breakdowns, operational accidents and preventative maintenance (pick inspection/changeouts)

It was found that it was 32% cheaper to mill coal compared to interburden with the lower interburdens (D8 to E8) being the highest costing partings to mill and the D5 coal seam recorded a production cost 70% cheaper. The SM was 37% cheaper to operate on coal and in interburden that was less than 2 m thick. In interburden thicker than 2 m, conventional mining would require blasting and thus the cost per bcm increased and the SM became 55% cheaper.

Real time data from a one-month collection period was used to investigate the instantaneous production of the SM when milling coal and interburden. Overall, the SM when milling coal and interburden was very effective with an advance rate of 16.5 m/min and 12 m/min respectively and achieved average rates of 4.2 bcm/h (pro-rated) for milling coal and 3 bcm/h (pro-rated) for cutting interburden. This data did not include operational delays and thus was used to predict the effectiveness of side casting loading method.

Side casting proved to be less time effective as normal loading due to the rehandle component using the loader. Even though the SM production rate was maximised, the loader’s production rate became the pinch point and made the overall side casting system less effective than direct loading.

Health and safety benefits of the SM include a reduction of whole body vibration to a Low risk rating (compared to high for dozers) and an improvement in ergonomics for the SM operator (compared to dozers). Noise generated from the SM was found to be approximately 3 dB lower than that of an unmodified excavator.

12.2 RECOMMENDATIONS

12.2.1 *Wild Oats*

- Increase target production rate by 13% for milling all coal.
- For interburden above the C8 coal level an increase of 13% of target production rate is recommended.
- Below the C8 coal level, the SM's production target should be reduced by 20% to better reflect the capabilities of the machine.
- Maintain long strike lengths – key success factor of SM reaching target. A series of three standard 150 m x 150 m blocks should be utilised to optimise the SM productivity.
- Side casting should not be used as the primary SM loading method due to the rehandle component and time inefficiencies. There are opportunities for implementation where:
  - strike length is limited;
  - access is tight;
  - the SM is under trucked; and
  - for topsoil stripping.
- Maintain sufficient truck allocation – key success factor of SM reaching target.
- Utilise the SM predominately on coal.
- Focus on scheduling the machine for stratigraphically high (close to surface) material, unless lower coal seams are stacked evenly on top of each other with minimal interburden present.
- Park the SM when appropriate material is not available to reach high production targets.
- Report and record production rates for each working area to further develop the findings from this project.

12.2.2 *Coal Mining Industry*

- Utilise in coal mines where seams are thick and with no/little interburden present.
- Utilise in combination with conventional mining equipment to increase productivity in turning areas and other applications that are difficult to operate the SM.
- Utilise in environmentally sensitive coal mines where blasting parameters are problematic.

- Research the feasibility of having a secondary SM unit to ensure a SM is always operating in a SM area. This could be a specific unit for coal – fitted with coal drum and a specific unit for waste – hard rock drum.
- Develop a strategic mine plan to better optimise mine/pit design around the SM fleet, using longer blocks in thick coal areas.

12.3 PROJECT COMPLETION & FUTURE RESEARCH

The project was deemed a success as the aim was fulfilled with the SM production data analysed and interpreted for productivity and economic feasibility. Material type and location, cost of loading, core risks and various loading methods of the SM were analysed and a recommendation for each aspect was given.

This project has the potential to be extremely beneficial to Wild Oats; however, as this was a reactive study (not a feasibility) and the SM was already operating on-site (initial capital expenditure was out of scope), further research is recommended. The following topics are for consideration for future applications of SMs in the coal mining industry:

- Undertake a pick/drum analysis for the material to be cut. This would analyse whether there is an increase in pick/drum wear as material hardness increases and suggest an appropriate design to be tailor made for each mining operation.
- Conduct a study investigating whether blasting the waste material effects productivity and operating cost.
- Conduct a full feasibility on the initial capital required and investigate against operating expenditure, to deduce if a cost saving occurs.

12.3.1 *Future of SMs in the Australian Coal Industry*

The future of SMs in the coal mining industry relies on the reduction of the initial capital cost of SMs through development of:

- more efficient picks and cutting drum to allow for high production rates on hard material (potential for overburden mining or pre-strip for draglines);
- other SM manufacturers to provide competition to Wirtgen; and
- trials of SMs for manufacturers to gather more information on the day-to-day challenges associated with SMs.

With automation becoming more prevalent and viable within the industry, it is believed the SM operation is easily transferrable to this GPS operated technology to further reduce operating cost. This is due to the mode of operation (straight, adjacent runs with turn around areas) replicating equipment being used in the agricultural industry (harvesters) which have been using automation for over a decade within Australia (Esquivel *et al*, 2006). Development of a coal-waste interface scanning technology would improve efficiencies, coal recovery and reduce dilution of the mineable reserve.

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APPENDIX 1 LOCATION OF WILD OATS

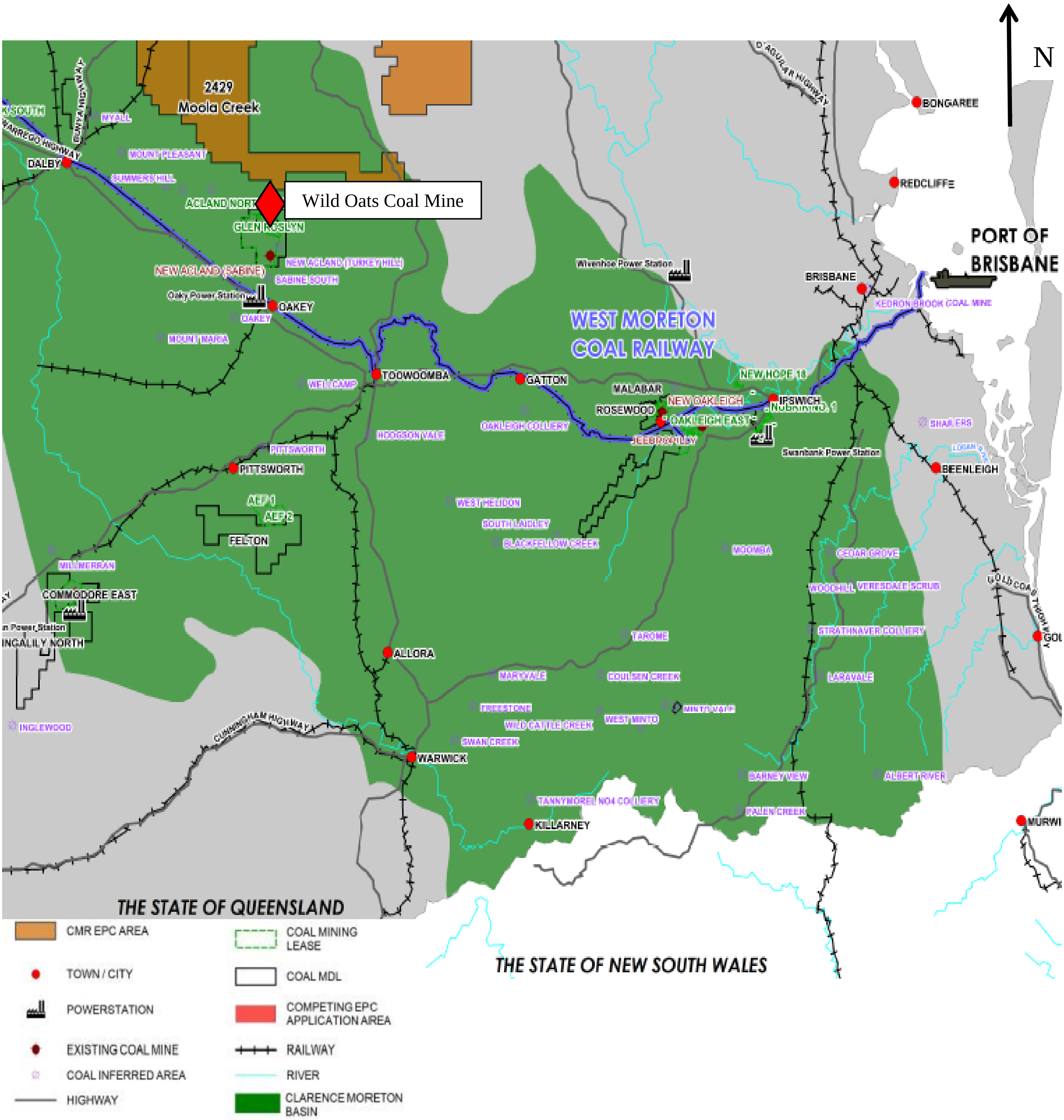

Figure A32. Location of Wild Oats Coal Mine within the Clarence-Moreton Basin (CMR, 2017).

APPENDIX 2 WINX SEQUENCE

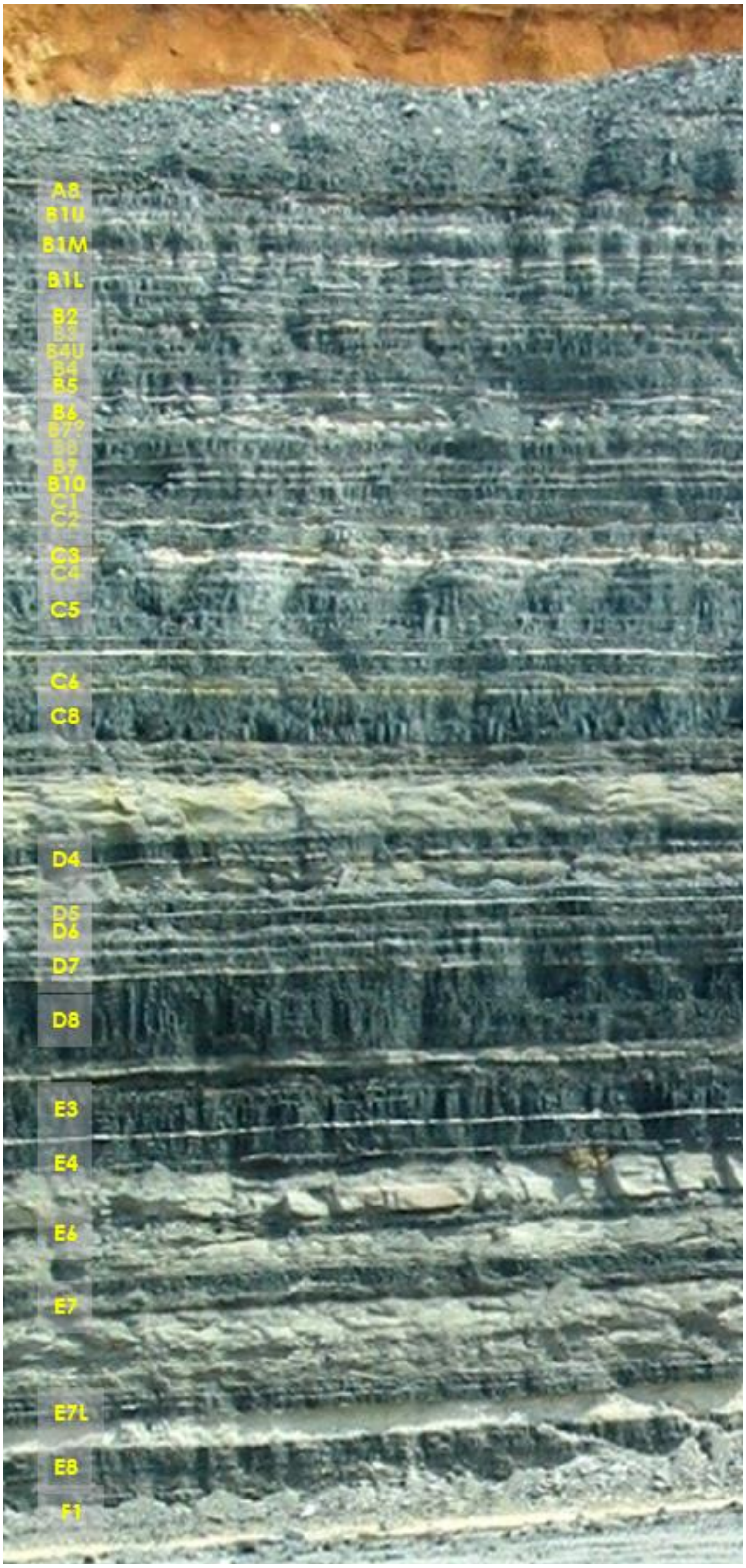

Figure A33. Full profile of Winx sequence (NHG, 2012).

APPENDIX 3 WORKING PRINCIPLE

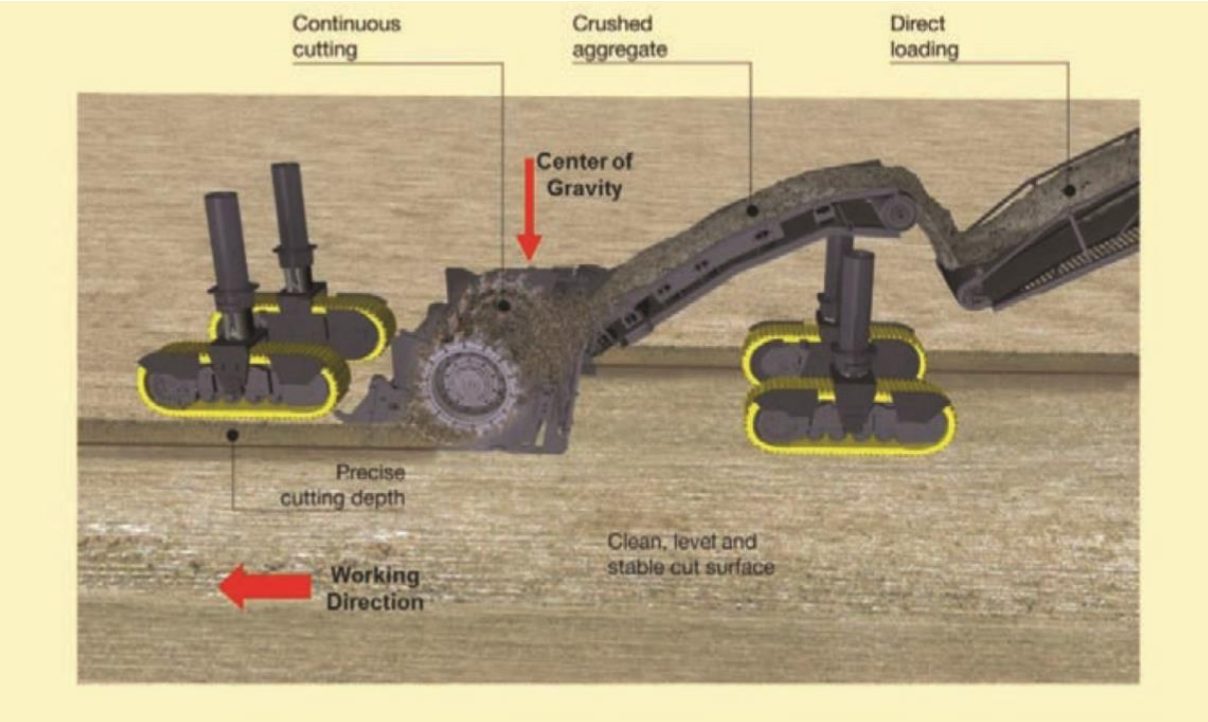

Figure A34. Generalised working principle of SM
(Volk, 2016).

APPENDIX 4 WIRTGEN SM4200

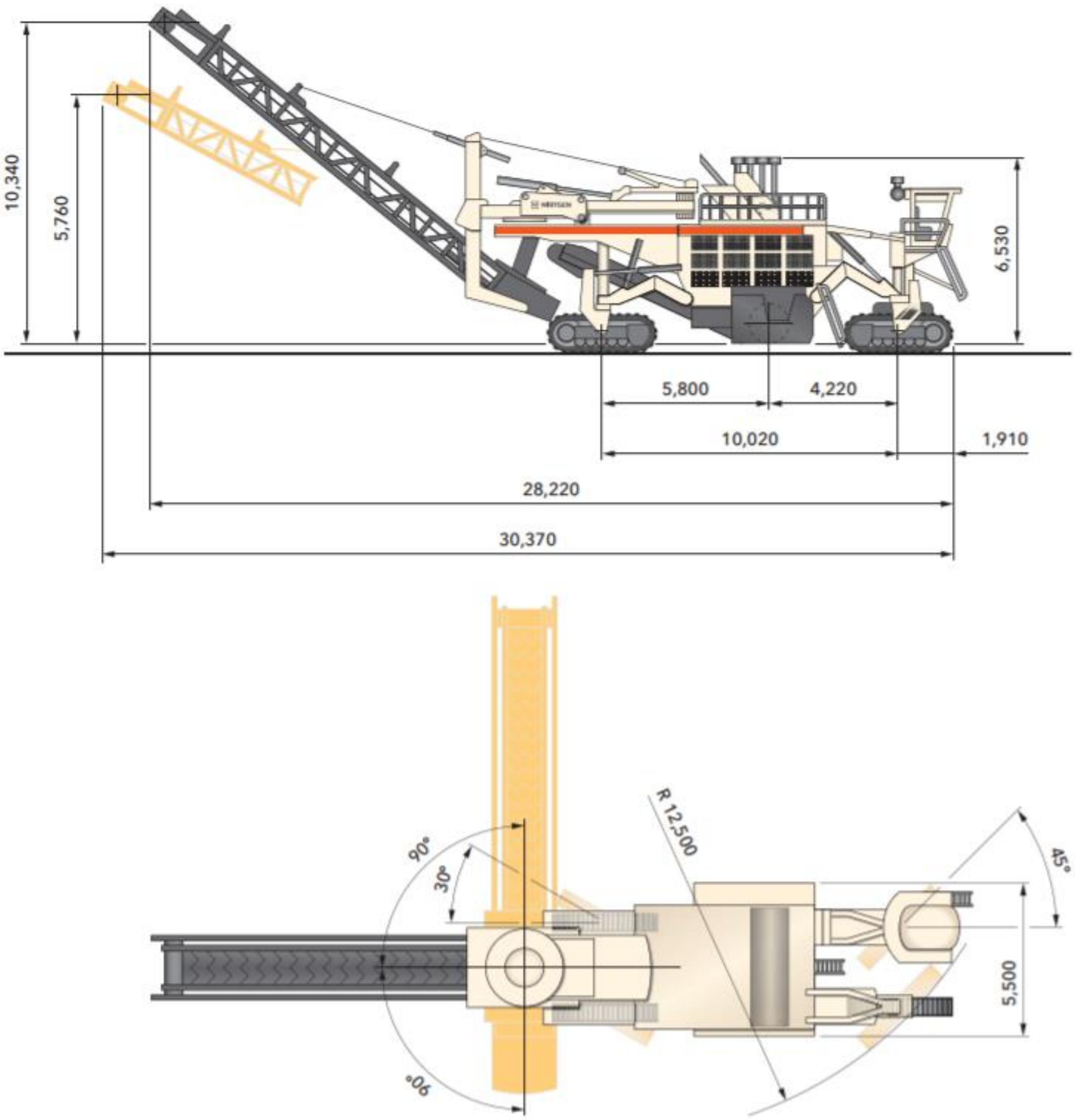

Figure A35. Wirtgen SM4200 model specifications and dimensions.

APPENDIX 5 LOADING OPTIONS

Figure A36. Windrowing method
(Wirtgen Group, 2017).

Figure A37. Direct loading
(Wirtgen Group, 2017).

Figure A38. Sidecasting method
(Wirtgen Group, 2017).

APPENDIX 6 OPERATING MODES

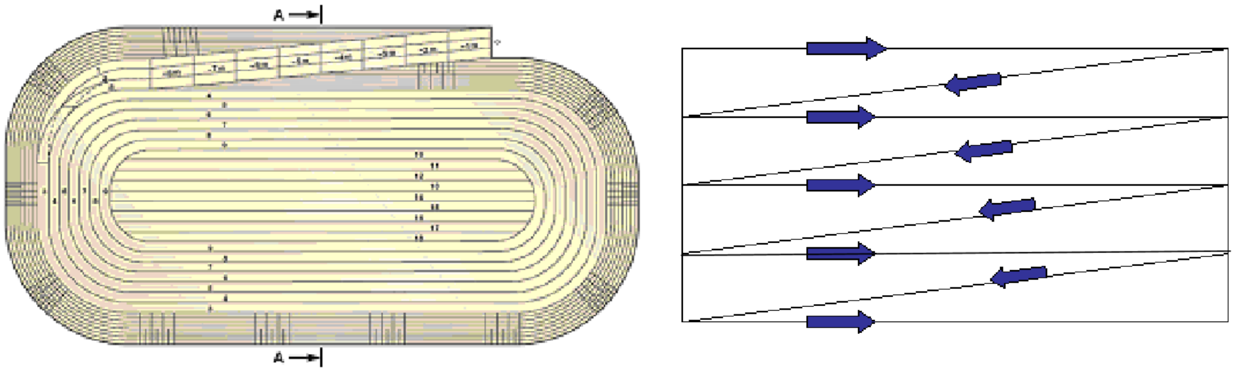

Figure A40. Continuous harvesting mode (left) and Empty travel back method (right) (Pradhan, 2009).

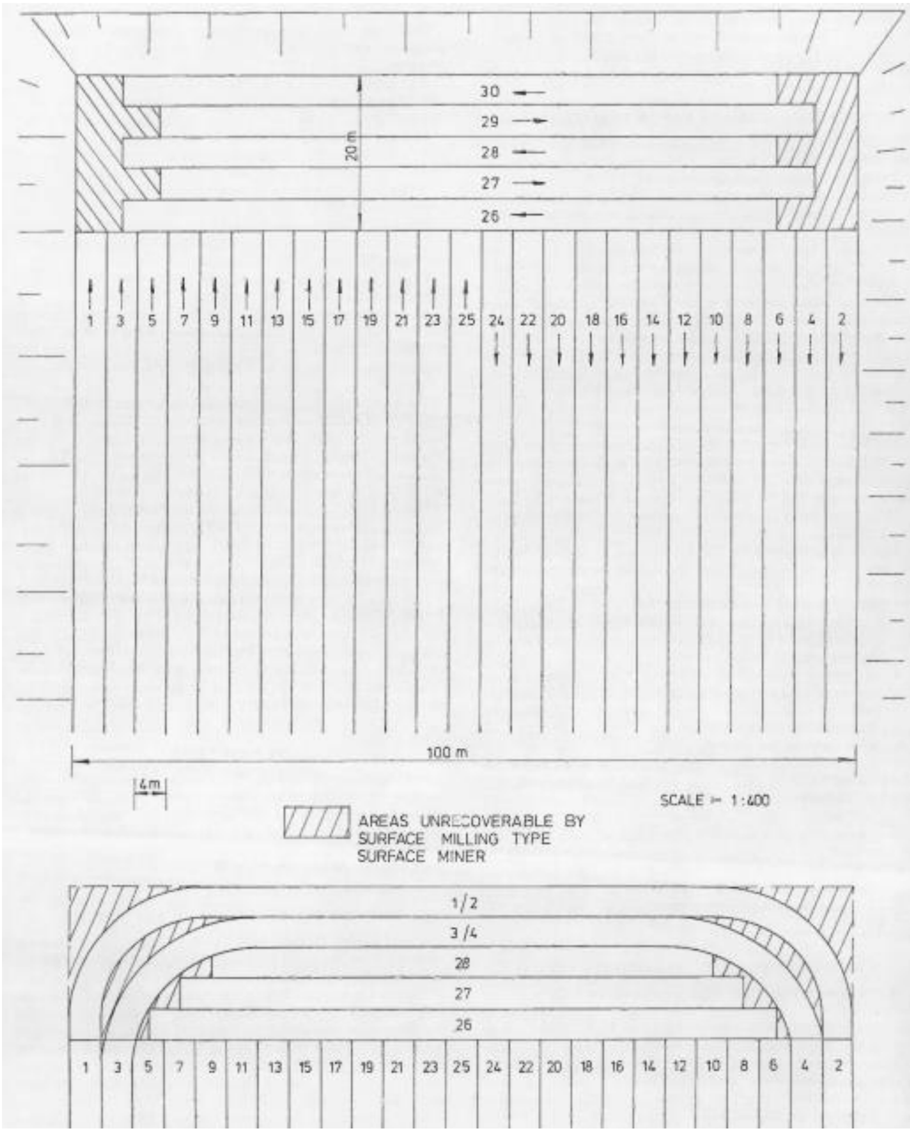

Figure A39. Turn back method cutting options (Wood, 1989).

APPENDIX 7 SURFACE MINER WORKING AREA

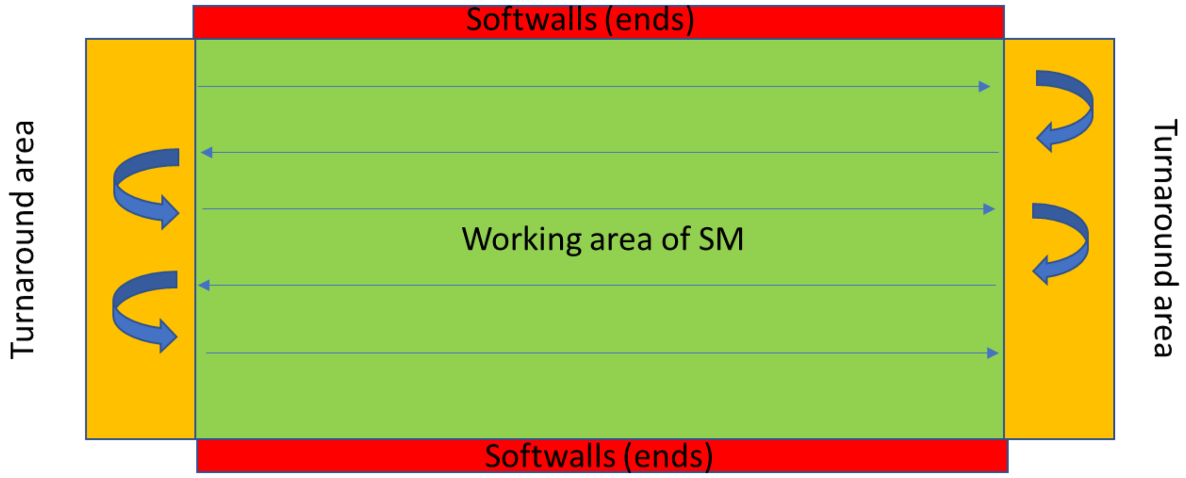

Figure A41. Working area of SM.

Figure A42. Softwalls created by SM
(Wirtgen Group, 2016a).

APPENDIX 8 KEY PERFORMANCE INDICATORS

Table A20
KPIs for the four-month trial at Wild Oats.

Evaluation KPIs	*Units*	*Month 1*	*Month 2*	*Month 3*	*Month 4*
Coal av. productivity	Pro-rata (t/h)	0.27	0.4	0.48	0.53
Coal max, productivity	Pro-rata (t/h)	0.5	0.75	0.9	1
Coal min. productivity	Pro-rata (t/h)	0.22	0.33	0.39	0.44
Interburden av. productivity	Pro-rata (bcm/h)	0.15	0.22	0.26	0.29
Interburden max. productivity	Pro-rata (bcm/h)	0.3	0.45	0.54	0.6
Interburden min. productivity	Pro-rata (bcm/h)	0.12	0.18	0.22	0.24
Noise limitations	dB	118	118	118	118
Mechanical availability	%	82	82	82	82

NOTE: production was pro-rated from 0 to 2381.

Source: NHG (2014)

Other KPIs assessed but no numerical limitation set (NHG,2014):

- whole body vibration in operator cab;
- top size coal produced to maximise CHPP efficiency;
- fine coal generation less than 2 mm not to exceed limitation of dozer/loader system;
- loss of dilution assessments compared to dozer/loader system;
- fuel usage per operating and meter hour;
- cutting bit replacement life in coal and interburden conditions; and
- consumable costs other than cutting bits.

APPENDIX 9 DAILY PRODUCTION DATA

Table A21
Example of raw data used for operational production analysis.

Date	*Pit*	*Strip*	*Block*	*Seam*	*Material*	*Truck*	*Loads*	*Production*
01/01/2015	South	12	8	E6	Partings	789	63	5,418
01/01/2015	South	12	8	E7	Partings	789	53	4,558
02/01/2015	South	12	8	E6	Partings	785VM	11	759
02/01/2015	South	12	8	E6	Partings	789	101	8,686
03/01/2015	South	12	8	E6	Partings	789	42	3,612
04/01/2015	South	12	8	E6	Partings	789	30	2,580
05/01/2015	South	12	8	E6	Partings	789	5	430
05/01/2015	South	12	8	E6	Partings	789	45	3,870
06/01/2015	South	12	8	E6	Partings	785	55	3,300
06/01/2015	South	12	8	E6	Partings	789	6	516
07/01/2015	South	11	7	C6	Coal	785CT	156	13,104
08/01/2015	South	11	7	C6	Coal	785CT	15	1,260
08/01/2015	South	11	7	C8	Coal	785CT	158	13,272
09/01/2015	South	11	7	C8	Coal	785CT	116	9,744
09/01/2015	South	11	7	C8	Coal	785VM	61	4,758
11/01/2015	South	11	7	C8	Coal	785CT	88	7,392
12/01/2015	South	9	5	E7	Partings	789	38	3,268
12/01/2015	South	11	7	C8	Coal	785VM	7	546
12/01/2015	South	11	7	C8	Coal	789	23	1,932
13/01/2015	South	9	5	E7	Partings	789	43	3,698
13/01/2015	South	11	7	C8	Coal	785CT	6	504
13/01/2015	South	11	7	C8	Coal	785VM	2	156
13/01/2015	South	11	7	C8	Coal	789	6	504
14/01/2015	South	11	7	D4	Coal	785CT	130	10,920
14/01/2015	South	11	7	D4	Coal	785VM	8	624
15/01/2015	South	11	7	D4	Coal	785	25	1,375
15/01/2015	South	11	7	D4	Coal	785CT	70	5,880
15/01/2015	South	11	7	D4	Coal	785VM	61	4,758
15/01/2015	South	11	7	D5	Partings	785VM	3	207
15/01/2015	South	11	7	D5	Partings	789	4	344
16/01/2015	South	11	7	D4	Coal	785	1	55
16/01/2015	South	11	7	D4	Coal	789	14	1,176
16/01/2015	South	11	7	D5	Partings	785	1	60
16/01/2015	South	11	7	D5	Partings	785VM	2	138
16/01/2015	South	11	7	D5	Partings	789	80	6,880
17/01/2015	South	11	7	D5	Partings	785VM	8	552
17/01/2015	South	11	7	D5	Partings	789	61	5,246
18/01/2015	South	11	7	D5	Partings	789	80	6,880
19/01/2015	South	11	7	D5	Partings	789	42	3,612
19/01/2015	South	11	7	D5	Partings	785VM	17	1,173
19/01/2015	South	11	7	D5	Partings	789	52	4,472
20/01/2015	South	11	7	D5	Partings	785VM	10	690
20/01/2015	South	11	7	D5	Partings	789	21	1,806
21/01/2015	South	11	7	D5	Partings	785	8	480
21/01/2015	South	11	7	D5	Partings	785VM	5	345

Source: NAC (2017)

APPENDIX 10 SM ACTIVITY

Table A22
Example of raw hourly data used for productivity analysis.

Shift	*Status*	*Name*	*Start Time*	*Duration (h)*
DS	Standby	Non Scheduled	01-06-17 6:00	12
NS	Standby	Non Scheduled	01-06-17 18:00	12
DS	Standby	Non Scheduled	02-06-17 6:00	0.97
DS	Ready	Harvest	02-06-17 6:58	0.37
DS	Ready	Loading	02-06-17 7:20	3.66
DS	Delay	Crib	02-06-17 11:00	0.9
DS	Ready	Loading	02-06-17 11:54	3.63
DS	Delay	Operator Change/Hot Seat	02-06-17 15:32	0.13
DS	Ready	Loading	02-06-17 15:41	0.02
DS	Ready	Loading	02-06-17 15:42	2.28
NS	Ready	Loading	02-06-17 18:00	6.52
NS	Standby	Non Scheduled	03-06-17 0:31	0.09
NS	Standby	Non Scheduled	03-06-17 0:37	5.38
DS	Standby	Non Scheduled	03-06-17 6:00	3.97
DS	Delay	Crib	03-06-17 9:58	0.69
DS	Ready	Loading	03-06-17 10:40	1.69
DS	Ready	Harvest	03-06-17 12:22	1.82
DS	Standby	Non Scheduled	03-06-17 14:11	3.8
NS	Standby	Non Scheduled	03-06-17 18:00	12
DS	Standby	Non Scheduled	04-06-17 6:00	0.93
DS	Ready	Harvest	04-06-17 6:56	0.01
DS	Ready	Loading	04-06-17 6:56	0.22
DS	Down	B/Down Other	04-06-17 7:09	0.13
DS	Ready	Loading	04-06-17 7:17	1.65
DS	Standby	Non Scheduled	04-06-17 8:57	9.04
NS	Standby	Non Scheduled	04-06-17 18:00	12
DS	Standby	Non Scheduled	05-06-17 6:00	0.61
DS	Ready	Loading	05-06-17 6:36	0.87
DS	Delay	Wait on Haul Truck	05-06-17 7:29	0.02
DS	Ready	Loading	05-06-17 7:30	0.56
DS	Delay	Wait on Grader	05-06-17 8:04	0.03
DS	Ready	Loading	05-06-17 8:06	0.27
DS	Delay	Wait on Haul Truck	05-06-17 8:23	0.25
DS	Ready	Loading	05-06-17 8:38	0.3
DS	Down	B/Down Hydraulics	05-06-17 8:57	0.02
DS	Ready	Loading	05-06-17 8:58	0.08
DS	Down	B/Down Hydraulics	05-06-17 9:03	1.55
DS	Ready	Loading	05-06-17 10:36	0.11
DS	Delay	Wait on Haul Truck	05-06-17 10:43	0.19
DS	Delay	Training	05-06-17 10:54	0.01

Source: NAC (2017)

APPENDIX 11 UNIT COST SURFACE MINER

Table A23
SM unit costs and assumptions used for coal analysis.

SM Model	*Units*	*Coal Average*
Coal Productivity	bcm/op h	750
Coal Productivity	t/op h	1,163
SM fuel consumption	l/h	165
Fuel price	$/l	1.03
SM fuel cost	$/h	203.94
SM lubrication cost	$/h	25.86
SM spare part cost	$/h	275.52
SM cutting tool consumption	pcs/h	0.4
Eng. h per Op h	(85% availability)	1.2
SM cutting tool cost	$	31.03
SM wear cost	$/h	16.38
SM operator salary	$/h	116.10
SM maintenance salary	$/h	116.10
Total SM operating cost	$/h	753.90
SM production cost	$/t	0.65

Source: Prochnau (2015) and NHG (2014)

Table A24
SM unit costs and assumptions used for interburden analysis.

SM Model	*Units*	*Interburden Average*
Coal Productivity	bcm/op h	750
SM fuel consumption	l/h	165
Fuel price	$/l	1.03
SM fuel cost	$/h	203.94
SM lubrication cost	$/h	30.17
SM spare part cost	$/h	321.44
SM cutting tool consumption	pcs/h	0.6
Eng. h per Op h	(72% availability)	1.4
SM cutting tool cost	$	36.2
SM wear cost	$/h	22.3
SM operator salary	$/h	135.45
SM maintenance salary	$/h	135.45
Total SM operating cost	$/h	1116.58
SM production cost	$/bcm	1.49

Source: Prochnau (2015) and NHG (2014)

APPENDIX 12 INSTANTANEOUS PRODUCTION DATA

Table A25
Example of raw data used for instantaneous production analysis.

Shift	*Fleet*	*Grade*	*Payload*	*Full*	*Empty*	*Time to load*
DS	785C_CT	S1201_C6_COAL	122.40	7:54:54	8:10:00	0:23:32
DS	785C VM	S1201_C6_COAL	106.30	8:18:13	8:39:00	0:08:43
DS	785C_CT	S1201_C6_COAL	34.50	8:19:43	8:20:15	0:01:30
DS	785C_CT	S1201_C6_COAL	128.10	8:21:28	8:32:08	0:01:10
DS	785C VM	S1201_C6_COAL	86.10	8:24:47	8:34:13	0:03:19
DS	785C_CT	S1201_C6_COAL	124.10	8:39:01	8:50:45	0:14:14
DS	785C_CT	S1201_C6_COAL	121.20	8:42:46	8:59:08	0:03:45
DS	785C_CT	S1201_C6_COAL	117.70	8:56:12	9:09:55	0:00:49
DS	785C_CT	S1201_C6_COAL	110.50	9:10:50	9:22:05	0:14:38
DS	785C VM	S1201_C6_COAL	109.50	9:13:43	9:24:05	0:02:53
DS	785C_CT	S1201_C6_COAL	114.80	9:16:45	9:27:30	0:03:02
DS	785C_CT	S1201_C6_COAL	64.80	9:32:39	9:50:42	0:15:54
DS	785C_CT	S1201_C6_COAL	122.60	9:41:42	9:53:30	0:05:05
DS	785C VM	S1201_C6_COAL	98.20	9:53:41	10:05:00	0:11:59
DS	785C VM	S1201_C6_COAL	92.80	10:00:36	10:11:34	0:06:55
DS	785C_CT	S1201_C6_COAL	121.90	10:12:44	10:23:55	0:12:08
DS	785C_CT	S1201_C6_COAL	122.00	10:16:18	10:27:16	0:03:34
DS	785C_CT	S1201_C6_COAL	111.90	10:19:38	10:29:11	0:03:20
DS	785C VM	S1201_C6_COAL	78.90	10:25:37	10:35:05	0:05:59
DS	785C VM	S1201_C6_COAL	97.90	10:33:04	10:44:20	0:07:27
DS	785C_CT	S1201_C6_COAL	37.50	10:35:42	10:35:46	0:02:38
DS	785C VM	S1201_C6_COAL	103.40	10:35:46	12:19:40	0:00:04
DS	785C_CT	S1201_C6_COAL	124.80	10:38:04	10:49:45	0:02:18
DS	785C_CT	S1201_C6_COAL	115.30	10:40:55	10:52:18	0:02:51
DS	785C_CT	S1201_C6_COAL	110.40	10:44:07	10:56:31	0:03:12
DS	785C VM	S1201_C6_COAL	153.10	10:49:14	11:13:19	0:05:07
DS	785C_CT	S1201_C6_COAL	136.70	11:13:22	11:15:00	0:24:08
DS	785C VM	S1201_C6_COAL	115.10	11:35:20	11:35:44	0:21:58
DS	785C VM	S1201_C6_COAL	103.00	12:02:25	12:12:25	0:27:05
DS	785C_CT	S1201_C6_COAL	117.60	12:17:11	12:27:25	0:14:46
DS	785C VM	S1201_C6_COAL	108.90	12:26:27	12:35:32	0:09:16
DS	785C_CT	S1201_C6_COAL	29.10	12:28:36	12:29:30	0:02:09
DS	785C_CT	S1201_C6_COAL	116.70	12:29:04	12:30:54	0:00:28
DS	785C_CT	S1201_C6_COAL	116.50	12:29:47	12:41:05	0:00:15
DS	785C_CT	S1201_C6_COAL	118.60	12:33:19	12:45:15	0:02:23
DS	785C VM	S1201_C6_COAL	99.50	12:36:36	12:48:05	0:01:00
DS	785C_CT	S1201_C6_COAL	113.60	12:43:40	12:55:25	0:07:04

Source: NAC (2017)

APPENDIX 13 JOB EFFICIENCY

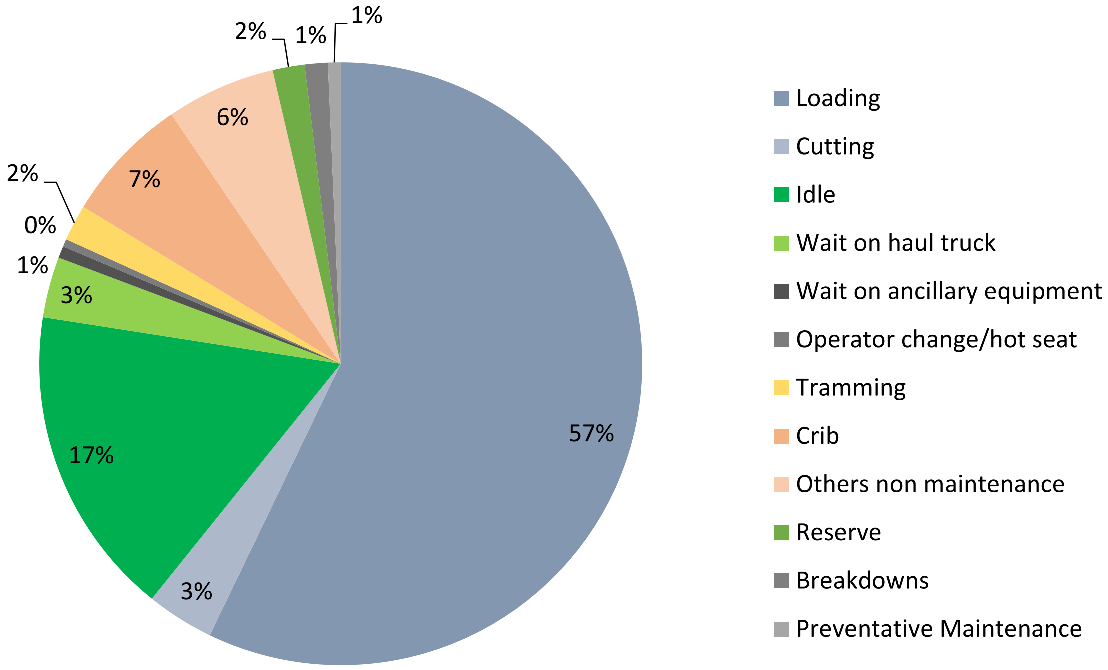

Figure A43. Job efficiency of SM for six-month period.

APPENDIX 14 OPERATOR VIEW

Figure A44. SM operator view (Prochnau, 2015).